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PICTORIAL DISPLAY DESIGN TO ENHANCE SPATIAL AWARENESS OF OPERATORS IN UNMANNED AVIATION

by

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13. ABSTRACT

In aviation**,** spatial awareness and spatial orientation are essential for performing the task of recovering from an unusual attitude. Degraded spatial awareness, particularly in extreme flight situations, may lead to lower operational effectiveness and to loss of equipment and, in manned aviation, loss of life. Therefore, improvements in spatial awareness are important in complex 3D environments, including both manned and unmanned aviation.

The main goal of this thesis was to determine whether a new prototype display design, called WEBER-Box, is a useful alternative or supplement to traditional flight instruments for unmanned aviation. In addition we combined the traditional flight instrument as well as the WEBER-Box with a colored-coded indication when the aircraft entered an unusual attitude.

In this experiment, the participants executed typical tasks of a UAV-operator. We investigated the influence of the WEBER-Box on UAV operator's orientation performance. The important results can be summarized as follows:

1. significant improvement in correctly solving the orientation tasks
2. significant reduction in time to solve orientation tasks
3. color coded indication of unusual attitude significantly decreased the response time and reduced the error
4. the proposed display design was accepted, interpreted, and used to solve 3D-orientation tasks efficiently

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PICTORIAL DISPLAY DESIGN TO ENHANCE SPATIAL AWARENESS OF OPERATORS IN UNMANNED AVIATION

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LIST OF ACRONYMS

AAA	Anti-Aircraft Artillery
AAR	Automated Aerial Refueling
ANOVA	Analysis of Variance
AVO	Air Vehicle Operator
EFIS	Electronic Flight Information System
HALE	high-altitude, long-endurance
HUD	heads-up display
HMD	helmet-mounted display
DoD	Department of Defense
MALE	medium-altitude, long-endurance
MANPADS	man portable systems
NASA	National Aeronautics and Space Administration
SA	Situation Awareness
SD	Spatial disorientation
STD	Standard deviation

LTC	Lieutenant Colonel
UAV	Unmanned Aerial Vehicle
USAF	United States Air Force
USN	United States Navy

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I. INTRODUCTION

Human performance in spatial orientation tasks requires spatial awareness and the skills of an operator to transition from the current spatial attitude into an acceptable spatial orientation and position. Degraded spatial awareness (SA), particularly in extreme flight situations, may lead to loss of equipment and reduced operational effectiveness. Accidents and loss of aircraft due to spatial disorientation (SD) are not uncommon in manned aviation. Loss of SA also occurs in unmanned aviation, even with operators on the ground. Surprisingly, losses in manned aviation over the last few years are low and decreasing but in unmanned aviation, they are high and increasing.

How to maintain and improve SA is one of the major issues in complex 3D environments. In particular, orientation tasks in 3D environments with many degrees of freedom are very difficult to accomplish (Previc & Ercoline, 2004). According to Tsang & Vidulich (2003) pilots are selected carefully and receive extensive training to maintain their spatial awareness, even in extreme fight situations.

Different classes of Unmanned Aerial Vehicles (UAV) systems operate in a wide variety of operational environments, from safe, remote locations to areas under immediate threat of enemy fire. This range of operational environments, combined with future plans for single-operators controlling multiple UAVs, leads to complex human-system interfaces.

However, the dynamic field of high-flying and Combat UAV demands skilled operators who are capable of controlling the aircraft remotely. For large UAVs, pilots are usually the first choice for this task.

The cockpit design of UAVs follows the guidelines of traditional flight instrumentation (McCauley & Matsangas, 2004). A legitimate question is whether a new prototype display design might improve spatial orientation, especially with an underlying color-coding feature when reaching an unusual attitude. McCauley & Matsangas (2004) also showed that maintaining spatial awareness and preventing spatial disorientation is a key factor when operating a UAV.

Since the improvement of the operational utility of UAVs, they have increased rapidly in the armed forces of many nations. They have proven to be valuable in recent military operations worldwide. However, the rise in UAV use has been accompanied by a very high mishap rate due to a number of different causes (Williams, 2004).

The main motivation for this thesis was to investigate the use of an alternative display design for UAV operators for the purpose of improving spatial awareness and thereby reducing mishaps. To evaluate this issue, a research questionnaire was sent to several US Air Force units and the information derived from that source helped to define the research objectives.

The main goal of the thesis was to determine whether a new prototype display design, called WEBER-Box, is a useful alternative or supplement to the traditional flight instruments for determining and correcting for unusual attitudes. The application specifically investigated was operation of a UAV such as Predator. Another objective was to determine whether non-aviator operators will perform as well as aviators operating a UAV, even in extreme flight situations or flight maneuvers, when supported with different types of attitude indicators. We conducted an experiment where the participants performed typical control tasks of a UAV-operator. The experimental task required participants to be aware of their spatial orientation and to judge their current attitude (pitch and roll orientation). This study investigated the potential of a new display design, the WEBER-Box, compared to the traditional flight instruments when performing spatial orientation tasks necessary to operate a UAV. The following research questions were addressed:

- Will the new display design help the pilot/operator to recognize the current attitude?
- Will the new display design help the pilot/operator to differentiate between a usual or unusual attitude?
- Will the new design help to prevent misperception of an unusual attitude when the UAV is not in an unusual attitude?

The core research question to be answered was, if the new design supports the recognition of the current attitude. An additional research question was, if it aids recovery when an unusual attitude exists and help preventing misperception of an unusual attitude when the UAV is performing normally.

II. BACKGROUND – COGNITION IN AVIATION

A. SITUATIONAL AWARENESS

SA is a complex mix of many different factors. In general it can be defined ”as the perception, understanding, and the ability to forecast the factors affecting the aircraft at any moment in time” (Moroze & Snow, 1999).

Endsley (1988) provided a first established definition. According to her, SA is “the pilot’s internal model of the world around him at any point in time.” It is derived from the aircraft instrumentation, the out-the-window view, and his or her senses. Individual capabilities, training, experience, objectives, and the ability to respond to task workload moderate the quality of the operator’s SA. She expanded in 1995 her definition by addressing for the first time three different levels. SA provides “the primary basis for subsequent decision making and performance in the operation of complex, dynamic systems…” At its lowest level the operator needs to perceive relevant information, next he has to integrate the data in conjunction with task goals, and at its highest level, predict future events and system states based on this understanding. Vidulich (1995) describes it succinctly as referring to the pilot’s cognitive understanding of the current situation and its implications. According to Jaslow (1998), SA is the knowledge of the aircraft’s location in space (position and attitude), awareness of the environment (terrain geography and features, weather-related conditions such as turbulence and icing), understanding communication (within the cockpit and via the air traffic controller), correct reading of the instruments, and knowledge of malfunctioning controls and/ or instruments. This definition provides the wide approach of SA. It also indicates that spatial orientation, as shown in a succeeding chapter, is only one part of SA, because it only describes the knowledge of the aircraft’s orientation in space (Gawron, 2004).

Endsley (2000) described this information coherence as an information gap (see Figure 1).

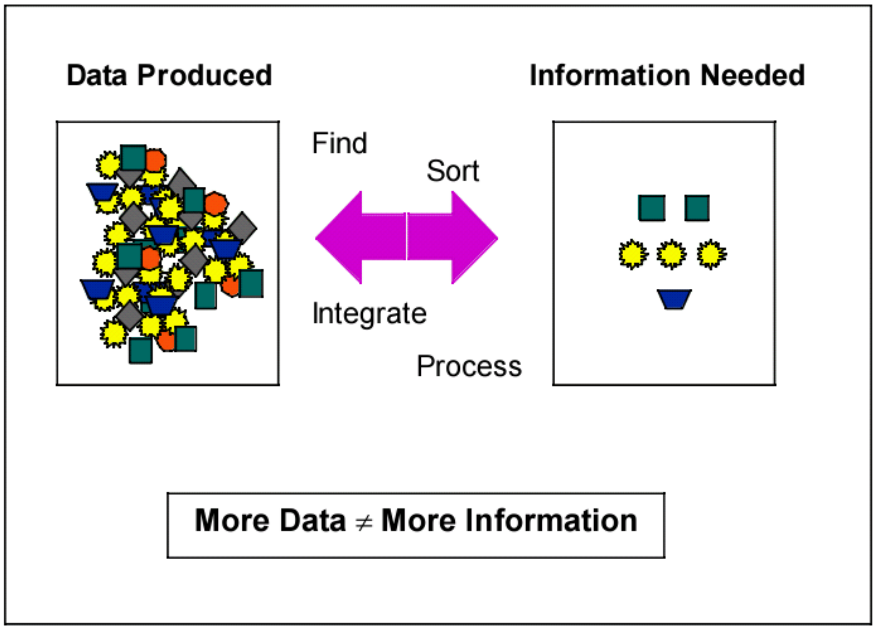

Figure 1. The information gap (Endsley, 2000)

In addition, Endsley (1999 and 2000) discusses three different levels of SA:

Level 1: Perception	The first step "is to perceive the status, attributes, and dynamics of relevant information in the environment" (Endsley, 1999), which is fundamental in a current situation. Without the perception of the most important information, the option of building an incorrect picture of the situation increases.
Level 2: Comprehension	Comprehension expands the first level by under-standing the importance of those elements. Combining, interpreting, storing, and retaining these information is gaining importance.
Level 3: Projection	Deriving lessons and consequences from the former levels enables the operator to project future events and actions.

The interaction, not only of the three levels of SA, but also the whole complex of SA can be illustrated with Figure 2.

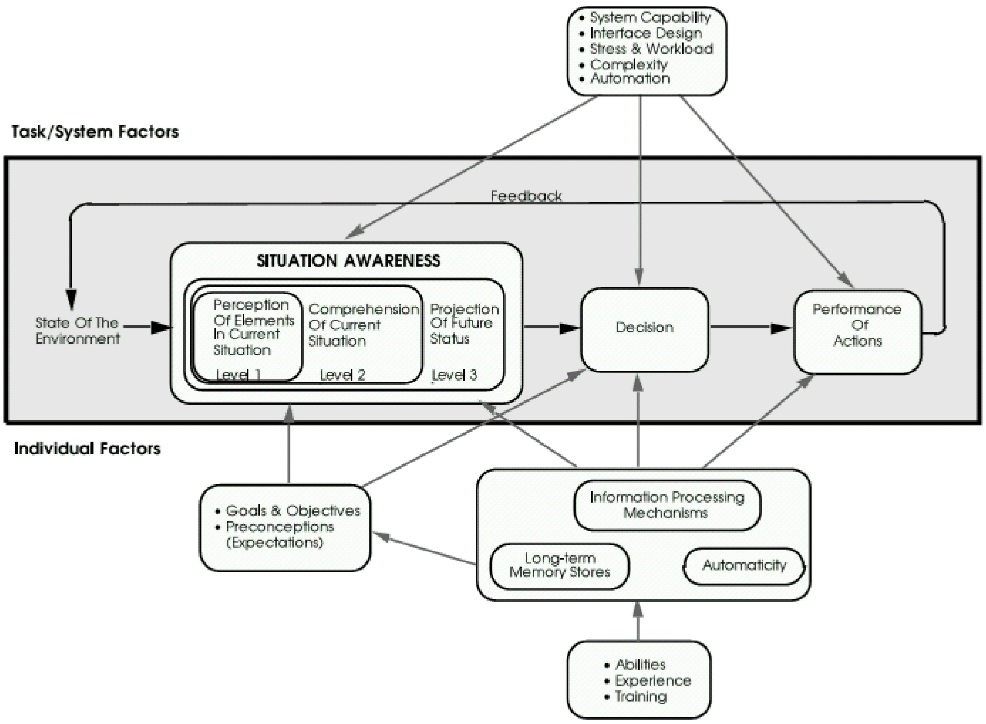

Figure 2. Model of SA in dynamic decision making (Endsley, 2000)

B. SPATIAL AWARENESS

To understand the term "spatial awareness" and to put it into the right context, it is important to know that it is only one component of SA. The other components of SA are system awareness and task awareness. Each of these components has real-world implications, spatial awareness for example for instrument displays.

Therefore spatial awareness is the understanding of the location, in 3D-space, of particular objects within a given environment. Consequently, spatial awareness is necessary in order to know, for example, the relative location of enemy targets, friendly or neutral forces. Increasing one's conceptual understanding of a particular 3D-space, also increases one's spatial awareness. It is important to gain a mental picture of the current situation because with this ability a pilot or operator is more able to predict the future situation and thus be able to operate the aircraft proactively (Wickens, 2002).

Wickens (2002b) also describes six different variables that are important for the mental picture of a pilot:

- pitch
- roll
- yaw
- altitude
- deviation from a flight path
- position along a flight path

Thus flight instruments which are displaying information about these variables in an appropriate manner contribute significantly to the spatial awareness of a pilot or operator of a UAV.

C. SPATIAL ORIENTATION / DISORIENTATION

In general, humans are adapted to maintain spatial orientation on the ground. Since they are not designed for the three-dimensional environment of flying, which is unfamiliar to their body systems, sensory conflicts and illusions are almost inevitable. Therefore, spatial orientation is sometimes difficult, even impossible to achieve (Antunano, 2003). Three sensory systems (see Figure 3 and Figure 4) provide the information necessary to maintain the equilibrium and determine where we are and how we are orientated:

- Visual system: The eyes, which sense position and movement based on optical information.
- Vestibular system: Organs of balance found in the inner ear that sense linear and angular acceleration and support posture and locomotion.
- Somatosensory system: Nerves in the skin, muscles, and joints, which, along with hearing, sense position and movement based on gravity, feeling, and sound.

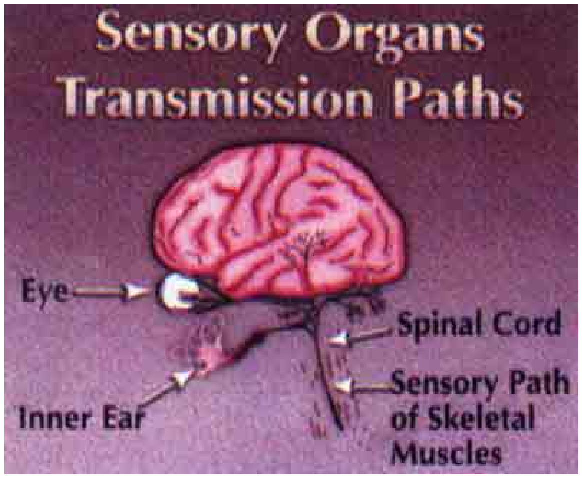

Figure 3. Spatial orientation (Antunano, 2000)

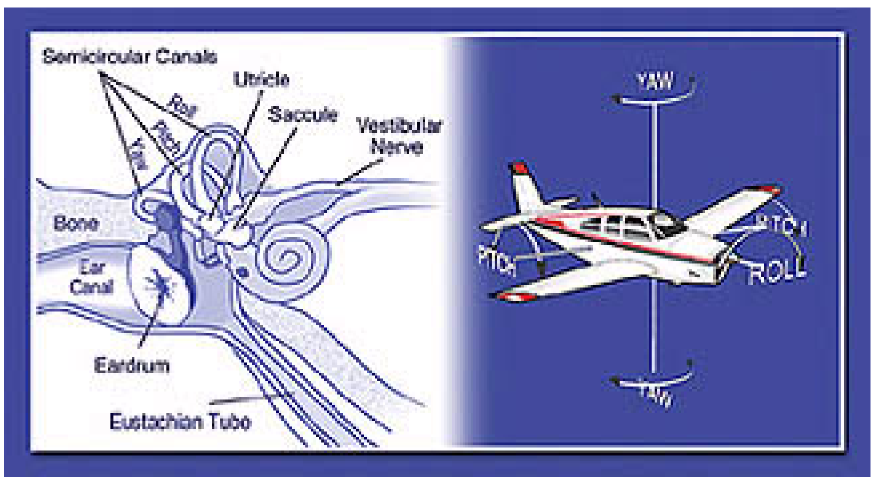

Figure 4. Spatial orientation (Antunano, 2003)

Spatial orientation in flight is difficult to achieve because the three different sensory systems vary in magnitude, direction, and frequency. Any differences or discrepancies result in a sensory mismatch that can produce illusions and lead to spatial disorientation. Good spatial orientation relies on the effective perception, integration and interpretation of their sensory information (Antunano, 2003). Thus one major issue is the question of appropriate countermeasures. The most common one is to "trust your instruments." On the other hand, flying by instruments increases demands on mental resources, task load, and disorientation stress (Braithwaite, Durnford, DeRoche, Alvarez, Jones, Hidgon et al., 1997).

SD is a failure “to sense correctly the position, motion, or attitude of the aircraft or of him/ herself within the fixed coordinate system provided by the surface of the earth and the gravitational vertical” (Benson, 1988). In addition, errors in perception by the aviator of his position, motion, or attitude with respect to his aircraft, or of his own aircraft relative to other aircraft, may also be embraced within a broader definition of SD. Any condition that deprives the pilot of natural, visual references to maintain orientation can rapidly cause SD. Regardless of a pilot’s experience or proficiency, sensory illusions can lead to differences between instrument indications and what the pilot feels the aircraft is doing.

SD in flight operations has been a common problem since the early days of aviation. Accidents continue to occur despite improvements in the display of information to the pilot. Even with improvements of manufacturing technologies, quality control, and aircraft maintenance, accidents still occur. Reasons for this fact are related for example to new technologies such as night vision goggles. Flight operations can now be executed in environments that have not been possible before (Benson, 1988).

Between 1990 and 1999, the United States Air Force (USAF) experienced 36 SD-related Class A mishaps. These have cost a total of $557M and even more important, the loss of 44 aircrew. These economic consequences of SD are enormous, both in cost of lost aircraft, lost aircrew, and cost of training new aircrew (Heinle & Ercoline, 2003). For example, in the period 1992 – 2000, SD was the cause of 20.2% of USAF Class A mishaps. Respectively US Army with 27% and US Navy with 26% rate in an equivalent period. But on the other hand, in a period of 1972 – 2000 USAF Class A mishaps have decreased in an overall rate from 2.5 accidents per 100.000 flying hours in 1972 to a rate of 1.0 in 2002. Despite this decrease, the rate of SD has only fallen from 0.5 to 0.25 and has remained constant in the last 15 years (Benson, 2000). Therefore, in general, SD is still the single most common cause of human-related aircraft accidents (Heinle & Ercoline, 2003).

The literature distinguishes between three different types of SD. About 80% of all Class A SD accidents are of *type I* and unrecognized. Pilots do not consciously perceive any manifestation of SD and most often it occurs when he/ she breaks a cross-check.

Most likely it also leads into a controlled flight into terrain. 20% of all SD Class A accidents are form *type II*. The pilot consciously perceives a manifestation of SD but may not attribute it to SD. Often, he suspects an instrument malfunction. The most well-known example is the Graveyard spin (see Figure 5). In this case the pilot realizes a conflict between the information displayed by the instruments and the feeling generated by the inner ear. The pilot has to decide which sensory system to believe. If he/ she trust his/ her inner ear, the aircraft may spin all the way to ground impact. The last type, *type III*, of SD, also called incapacitating SD, is the least common, known and understood. Few written reports exist at all, but it is known through experience and pilot reports. An example is named “giant hand illusion” (see Figure 6). Sometimes pilots feel that they are unable to move the controls in one direction, although they are capable of moving the controls in any other direction. A suggested countermeasure is to remove the hands from the controls and try it again by only using fingers without arm movements. Even a technical inspection after the flight showed no evidence of a technical malfunction and it is not possible to duplicate the problem (Heinle & Ercoline, 2002).

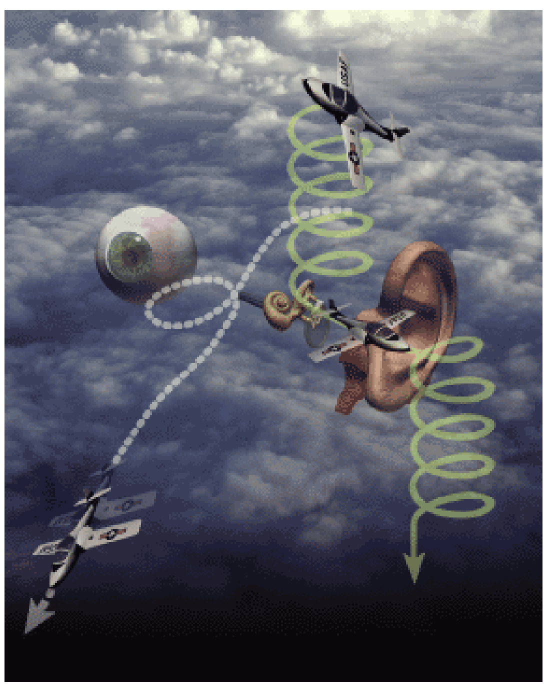

Figure 5. Graveyard Spin (Heinle & Ercoline, 2002)

Figure 6. Giant Hand Illusion (Heinle & Ercoline, 2002)

Each type of SD affects the pilot in a different way, and each should be thoroughly understood by the pilot before he or she experiences them in flight. Although the phenomenon of SD has been described and documented by many, both researcher and aircrew, since the earliest days of aviation, a complete understanding of the complex mechanisms and interactions has remained elusive.

According to Benson, 2002, the human factors and aero-medical community also has to be aware of SD in virtual reality and in operating UAVs. He defines SD as a misperception of the key elements in the flight environment. These key elements may include navigation, weather, tactics, nature of threats, aircraft systems, and spatial orientation. The task of piloting a UAV may be sensitive to SD, especially in cases of highly maneuverable vehicles, such as Combat-UAV where information is provided by optical and other sensors, and in extreme environmental conditions, like high wind speeds. In these cases, he concludes, there is a considerable potential for pilot disorientation and loss of control. Several factors, like restricted field of view, and lags in the display of information can be causes of mishaps. In addition, there is also the lack of motion stimuli to the operator’s body, in contrast to manned aviation. Unlike in conventional aviation, SD is widely underestimated for unmanned aviation. Since unmanned aviation lacks the direct physical perception and feedback, we expect that improved display concepts will contribute to a better spatial awareness and, hence, will decrease the potential for SD. A 10-year cross sectional review of human factors in UAV mishaps within the U. S. Department of Defense (DoD) supports Benson’s position. Interestingly, the outcome of this DoD-review is that the misperception error was present in 5% of all UAV mishaps.

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III. COCKPIT AND DISPLAY DESIGN

A. GENERAL PRINCIPLES DISPLAY DESIGN

The design of flight instruments and the cockpit panel have a long history, beginning with Elmer Sperry and the Airborne Gyro (Hughes, 1971). Even in the earliest powered flights, keeping the simple planes steady was difficult. The addition of gyroscopes in 1914 brought new instruments to the cockpit, helping the pilot to maintain steady control. Gyroscopes and their derivatives remain an important part of flight technology. Basically they have not changed since the beginning of aviation. Moreover, they have been, and still are, the pilot's main source of information. They are his tool for flying in an usual attitude, recovering from an unusual attitude, and for preventing mishaps.

Traditional cockpit design and flight instruments have almost always been arrayed with the most important instruments in the shape of a T (see Figure 7). This configuration can be found in a wide variety of aircraft from the beginning of aviation to the latest models of aircraft.

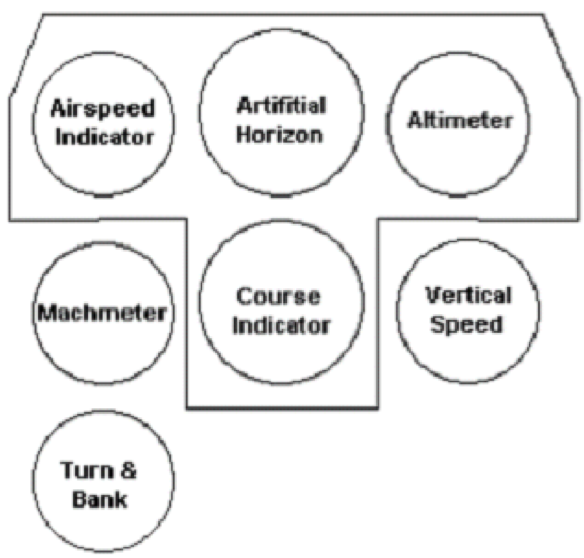

Figure 7. Basic layout of flight instruments (Anderson, 2002)

The center spot is always reserved for the artificial horizon or attitude indicator, which is not only one of the oldest instruments but also one of the most important. It provides information to the pilot about his current situation in space and therefore displays the flight attitude relative to the earth (see Figure 8). Pitch attitude is indicated by up and down motion of the sphere with respect to horizontal reference. Roll attitude is indicated by rotational motion of roll pointer with respect to the fixed roll scale located at top of the display.

Figure 8. Traditional attitude indicator (screenshot of X-Plane ™ flight simulation)

The evolution of aviation from the beginning with the Wright brothers' to modern aviation has brought some significant changes in the capabilities of the aircraft (Tsang & Vidulich, 2003). Besides the instruments, which basically remained the same, other factors like speed of the aircraft, especially for fighter aircraft, have changed. The demands on the pilots have thus increased, the workload is higher, and the task is more complex now.

With the development of new technologies in flight instrument design, there has been a shift away from individual displays like altimeter, airspeed indicator, or turn-and-bank indicator, towards integrated displays in which most of the information comes from a common source like a heads-up display (HUD) or helmet-mounted display (HMD).

Independent of the state-of-the-art display design, three basic issues can be "applied to the design and modification of primary flight and navigation instruments in the context of situation awareness assessment" (Andre, Wickens & Moorman, 1991):

- Display perspective: two- vs. three-dimensional
- Frame of reference: inside-out vs. outside-in
- Visual display monochrome vs. color

Many displays, like traffic, weather, or navigational displays, are two-dimensional with a "God's eye" plan view of the earth. On the other hand, flying an aircraft is much more related to a three-dimensional task. In this context, three-dimensional means the use of "perceptual depth or distance cues to create a three-dimensional image (Wickens, 2003)."

An important feature of 3-D displays is the frame of reference or the viewpoint from which a selected part of interest is presented (Wickens, 2003). Thus the point of view is important for a comparison between flight instruments. Previc & Ercoline, 1999, describe the fundamental differences between the first two types of attitude presentation for an aircraft in the following way:

- *Egocentric* or *Immersed* view point: This type is also known as *"inside-out"* or *"moving horizon"* or *"moving outside world"*. The outside world is presented from the inside perspective of an aircraft to the outside world (see Figure 9, right). The human is fixed in space and the world around him moves.
- *Exocentric* or *tethered* view point: This type is also known as "outside- in" or "moving aircraft". The perspective is from the outside world into the aircraft. This type of attitude presentation is rarely used for UAVs (see Figure 9, left). The world is fixed and the human moves.
- *Coplaner* view point: It shows a top-down lateral view and a vertical profile view, which can also have a side view or a back view (Wickens, 2003). Therefore it is a 2-D display, contrary to egocentric or exocentric that are 3-D display designs.

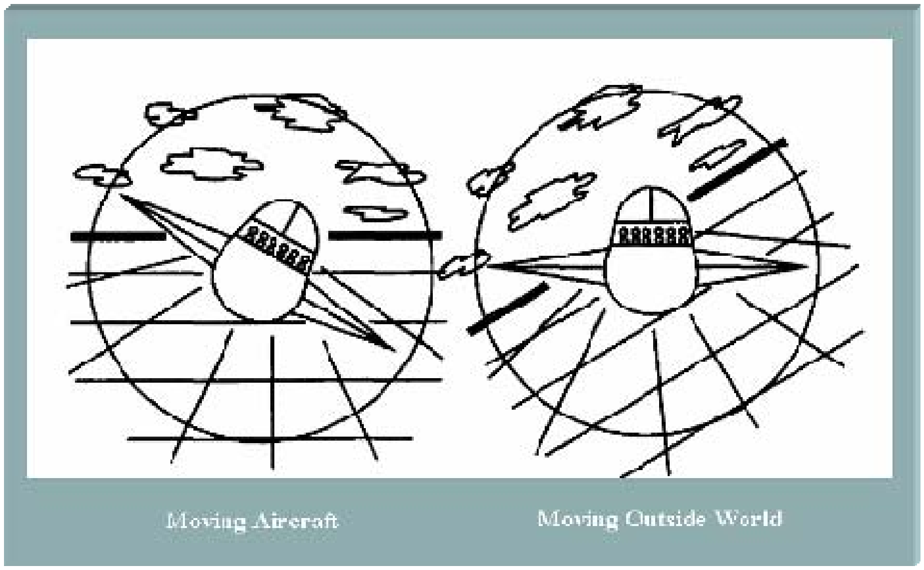

Figure 9. Fundamental differences of attitude representation for an aircraft (Previc & Ercoline, 1999)

According to Clay, 1993, many aircraft accidents are due to SD problems of the pilot and to an additional wrong interpretation of the flight instruments. One of the major challenges for flight instrument display is the tremendous data flow and information available from all of the instruments. Additionally, the priority of recalling the information changes with every task. In addition, flight instruments are normally not very intuitive (Previc & Ercoline, 2004). On the other side, multifunctional instruments and the “glass cockpit” have been developed. This approach may lead to an overload of the pilot/ operator because more information is available, the number and complexity of display pages has increased. Furthermore, with an increasing number of warning signals like audio or visual, status displays, flight path controls, only to mention a few, the human processing ability may be exceeded (Mejdal & McCauley, 2001). As a result, the requirements for developing new display designs or improving existing display designs become important. This display design challenge is taken in a new direction when UAVs are taken into account. For this purpose, display designs have to be less abstract and intuitively understandable for an operator on the ground.

The visual impact of color is strong and has been used in simple display applications since before the Second World War. The advantage of color for flight instruments is enhancing the presentation of information and gaining user acceptance. Color has proven effective when a lot of information must be presented. Two different applications of color-coding are widely used. First, color can be used to signify quantity, that is, to categorize data. The airspeed indicator is an example for this type of application. Secondly "qualitative color displays classify data by type or condition and are often used to convey status information" (Stokes & Wickens, 1988). For this application, color can be used to facilitate selective attention. It can act as an attention cue for the pilot who will never be able to monitor all his displays at the same time with the same level of attention. Typically colors for danger, caution, or advisory information, are red, amber, or green, respectively (Stokes & Wickens, 1988).

B. INSIDE-OUT VERSUS OUTSIDE-IN DISPLAY DESIGN

There is a general discussion between researchers as to which type of design of attitude presentation human beings prefer. One very early approach to utilizing an exocentric instrument design was a study by Hennessy, Lintern & Collyer, 1981, that used an exocentric view on an aircraft model to facilitate the flight training of pilots. Four different visual displays were evaluated for their effectiveness in the acquisition of flight tasks in a flight simulator. The experimental displays were,

(a) wide-field-of-view (160°) with horizon and checkerboard ground plane

(b) narrow-field-of-view (48°) with horizon and checkerboard ground plane

(c) an outside-in view of an airplane, also referred by the term "unconventional visual display"

(d) a display that consisted only of traditional flight instruments.

The participants were flight students who had to learn basic flight tasks in a simulator. The experiment was conducted in form of 20 trials (4 per display type). The researchers were particularly interested in the transfer of training in terms of how accurate a flight student could perform certain simple flight maneuvers. The key finding was that the students were able to learn flight maneuvers faster when using the outside-in display. Furthermore, the results showed that it is advantageous to have an external point of view for perceiving and understanding flight behaviors.

Previc & Ercoline (1999) presented additional findings on outside-in flight displays, claiming that they are superior at preventing roll-reversal errors during normal flight and in recovering from extreme flight situations. They state that “Although outside-in attitude displays have been, and continue to be, flown throughout the world, the majority of military and civilian aircraft have failed to adopt this format” (Previc & Ercoline, 1999). One of their conclusions is that even experienced pilots do not show a clear advantage with an inside-out attitude display with which they have trained extensively. In contrast, pilots trained on an outside-in format show overwhelming advantage in recovering from unusual attitude.

Self, Breun, Feldt, Perry & Ercoline, 2002, conducted a study for students in an introductory flight course at the U.S. Air Force Academy. They were tested on three different display symbologies:

(a) moving horizon symbology (egocentric viewpoint)

(b) moving plane symbology (exocentric viewpoint)

(c) arc-segment attitude reference symbology.

The researchers evaluated the time a student needs to give a roll-input in order to correct a certain spatial orientation of the aircraft as their main parameter of interest. This study found that the exocentric “outside-in” attitude display and the arc-segment attitude reference symbology were superior in reducing the time of roll-inputs in normal flights.

Tsang & Vidulich, 2003b, confirmed the former findings that pilots prefer an exocentric or outside-in view of the world.

C. PICTORIAL DISPLAY DESIGN

Research on pictorial display design began in early 1990s when National Aeronautics and Space Administration (NASA) conducted a series of experiments in order to determine if landing and taxing approaches of commercial aircraft and Space Shuttles may benefit from an external view of the own aircraft. Additionally Parrish, Busquets, Williams & Nold, (1994) conducted an experiment to evaluate certain display types, including a pictorial display design, which is also called “pathway in the sky” or “highway in the sky”. The objective was to evaluate and compare spatial awareness components of pilots using various display concepts. These four are:

(a) conventional electronic flight information systems (EFIS)

(b) EFIS and speech commands

(c) pictorial “pathway in the sky” display with 70° field-of view and

(d) a pictorial “pathway in the sky” display with 40° field-of view.

The pictorial display was a computer rendered graphic of an out-the-window scene with a flight path that was displayed as green goalposts with width and height in correspondence with the input from the electronic landing system. The results showed greatly improved subjective rankings of the pictorial design in terms of reduced workload, effort to monitor traffic and overall ranking. The objective measurements reveal a significant decrease of maneuver errors in all monitored categories.

This result is also supported by Ercoline, DeVilbiss & Evans (2004) because the pictorial design benefits the pilot’s spatial orientation. The configuration of the display appears more like the real world because a symbolic path is used to represent “the desired vertical and horizontal trajectory relative to Earth’s surface as opposed to command steering bars or a single command steering cue (Ercoline et al., 2004).” In addition, the pictorial display is appreciated by novices and experienced pilots.

D. THE WEBER-BOX

The WEBER-Box is a design concept for flight instruments that emphasizes a three-dimensional exocentric view of a virtual aircraft (Weber, 2006). He proposed in his thesis a new human-centric design approach for a 3D-flight instrument based on “avatar” concepts. Weber (2006) combined an exocentric design with pictorial metaphors of the current spatial orientation. By animating the entire scene, a story is being told about what happens during a flight maneuver. In this context, it is a “miniature abstract virtual world” that represents the actual spatial situation of the aircraft. The avatar “lives” in this virtual world. The display representing the aircraft is a 3D wire-frame model that hovers inside an abstract box and replicates all the basic motions of the real aircraft. The frame of reference is a coordinate system, consisting of X-, Y-, and Z-axes. Altitude is represented by a 3D bar along the Y- axis. The aircraft's movement relative to the ground is displayed by moving objects along the X-/Z- plane (see Figure 10 and 11).

Weber (2006) conducted two experiments, which found strong evidence for improvement of spatial awareness and pilot's performance in extreme flight situations. His findings were that the participants were able to judge the spatial orientation of their own aircraft about three times faster, compared to traditional flight instruments. The time needed to recover the aircraft from unusual attitudes improved by about 70%. Furthermore, he found no statistically significant differences in terms of performance improvement between pilots and non-pilots. Thus, operators of any experience level might benefit from the design of the "WEBER-Box".

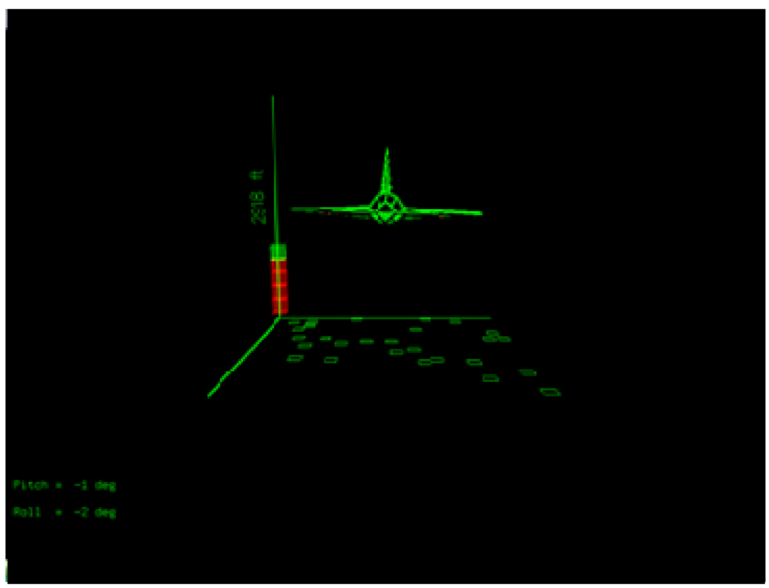

Figure 10. Screen shot of the WEBER-Box

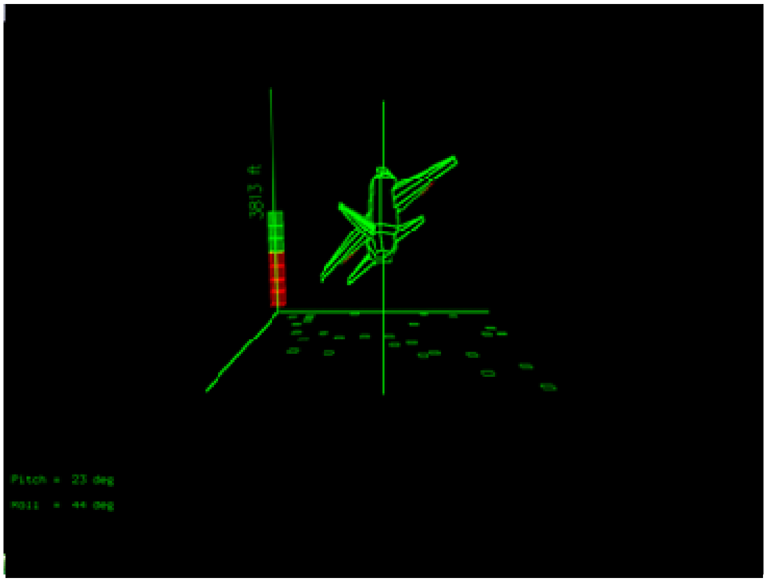

Figure 11. Screen shot of the WEBER-Box

Studies show that maintaining spatial awareness and preventing SD is becoming more and more an issue when operating UAVs. Current UAV controls rely on traditional flight instruments, which are inherently difficult to understand and demand a high degree of training (McCauley & Matsangas, 2004). On the other hand, human-centric display design is likely to substitute or supplement traditional flight instruments in the future. The outside-in display formats, combined with pictorial visualization seems to be promising to support and improve spatial awareness for operators of UAVs. The design concept of the WEBER-Box combines those display principles.

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IV. UNMANNED AERIAL VEHICLES

A. HISTORY AND OVERVIEW

Traditional aircraft have an important disadvantage or weakness. They have to be piloted by humans. Therefore there are negative consequences which have to be considered. In case of a crash, you not only loose equipment worth millions of dollars but also may loose the pilot. Other negative outcomes in military operations include the pilot and aircrew being taken as prisoners of war or hostages, which could have a serious impact on public opinion or the way a conflict has to be fought.

Thus, the idea of developing uninhabited or unmanned aerial vehicles arose. Since 1964 the United States Military has spent billions of dollars researching, developing and constructing countless types of UAVs. The United States Air Force has used UAVs for reconnaissance and surveillance at very long ranges up to 3,000 miles away. The core idea is to provide the warfighter with intelligence information and a precise delivery mechanism for smart area weapons, non-lethal payloads, as well as other cargo. Recently UAVs have also been established by the US Army and Marine Corps as tactical assets on the battlefield. Figure 12 provides a good impression of the actual size of a UAV Predator and Global Hawk compared to a Boeing 737 and therefore how far the development for large UAVs has already gone.

Figure 12. Sizes of UAV Predator and Global Hawk compared to a Boeing 737 (Picture by Northrop Grumman)

On the other hand, the latest and additional development points into the direction of Micro UAVs which can be launched, for example, in urban warfare.

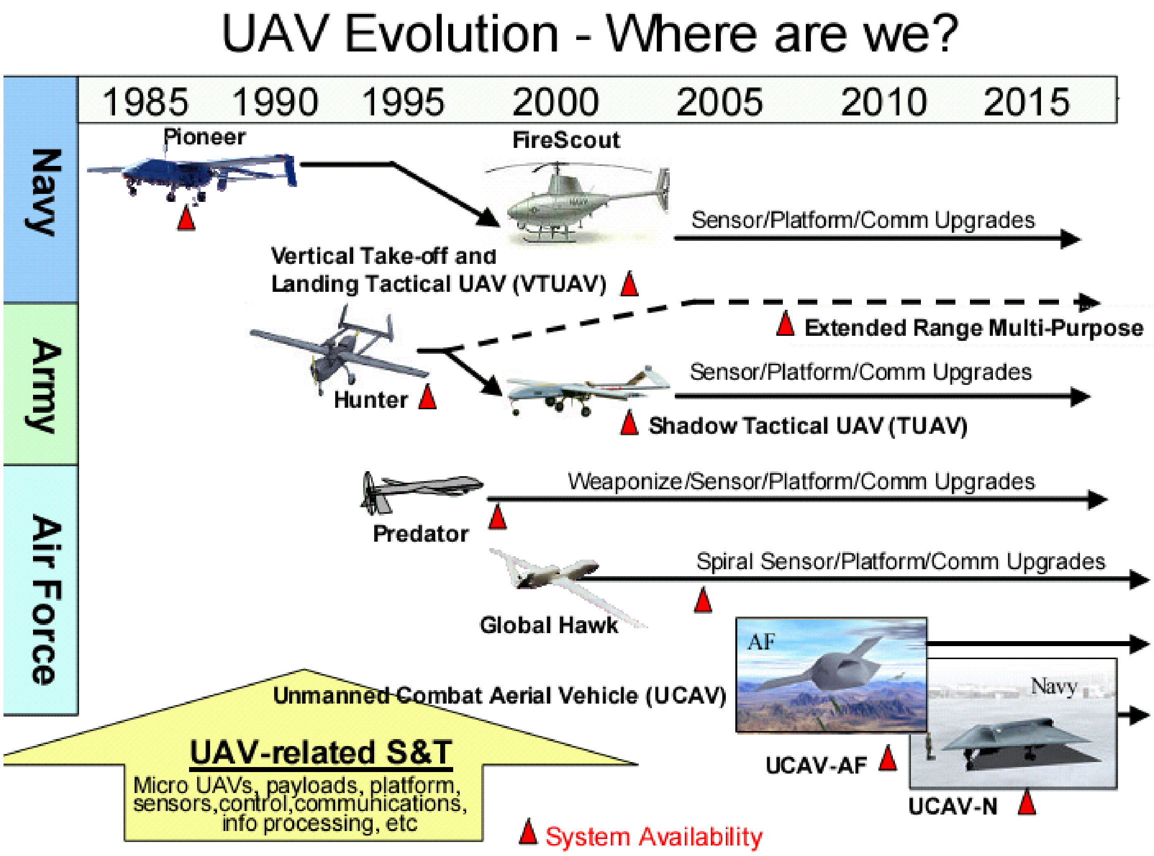

Figure 13. UAV Evolution – Where are we? (AUVSI, 2001)

There is not only the question “Where are we?” but even more interesting is the question “Where are we going?” Currently under development is the Automated Aerial Refueling (AAR) that could demonstrate for the first time a UAV’s ability to autonomously maintain a permanent refueling station behind a tanker aircraft. This extends the range of a UAV tremendously because now only the crew in the GGS has to be exchanged but the UAV can continue its mission.

Even the goals for developing and building future UAVs are determined, there are still concerns (see Table 1) that have to be taken care of (Thompson, 2000).

Datalink Communica-tions	1. Loss of control due to enemy jamming or signal manipulation 2. Long connectivity lapses due to distance, satellite location, or friendly mutual interference 3. Limited amount of frequency bandwidths to accommodate large numbers of secure links for multiple UCAV operations
Air Refueling	1. Transoceanic deployment distances and communications 2. Risk to KC-135 or KC-10 high-value assets 3. Tanker joinup and multiaircraft air refueling
Operator Situational Awareness	1. Number of aircraft per operator or operators per aircraft 2. Air traffic control (ATC) and enemy airspace deconfliction from other aircraft 3. Threat reactions for visual antiaircraft artillery, infrared surface-to-air missiles, or enemy aircraft
Emergencies	1. Less capability to rapidly assess and correct aircraft problems 2. Unable to see damage, feel small vibrations, or smell smoke 3. UAV-capable alternate airfield recovery due to fuel or weather

Table 1. Future UCAV concerns (Thompson, 2000)

B. ACCIDENTS

High mishap rates are often cited as a deterrent to a wider adoption of UAVs into future force structure. Over the last five decades, investments in manned aircraft reliability have been made to drive equipment failures to near zero. This progress implies that a considerable reduction in UAV accident rates due to technical failure also can be obtained with reasonable investments. On the other hand, it is also likely that the human in the loop contributes as a main source of failure and high mishap rates for both manned and unmanned aviation. A significant contributor to UAV mishaps is the experience level of UAV operators and maintainers.

Williams (2004) classified UAV accident data into the categories of human factors, aircraft, and unknown. He analyzed explicitly the data of the following UAVs: Hunter, Shadow, Pioneer, Predator, and Global Hawk, which are currently in use in the American Forces. His findings are that the involvement of human factors was high, in a range from 21% to 68%, depending on the type of UAV. Various human factors issues have been observed, including handing over a UAV from one pilot to another, launch and recovery, display issues, and disorientation.

DoD (2005) compared in its roadmap 2005 – 2030 the UAV mishap rate with the mishap rate of the F-16 (see Figure 14) of class A mishaps. These are the mishaps resulting in the loss of the aircraft, human life, or causing $1,000,000 in damage. It illustrates the mishap rate after similar numbers of flying hours have been accumulated. This Figure shows significantly that the mishap rate of today's UAV is comparable with the mishap rate of early manned military aircraft.

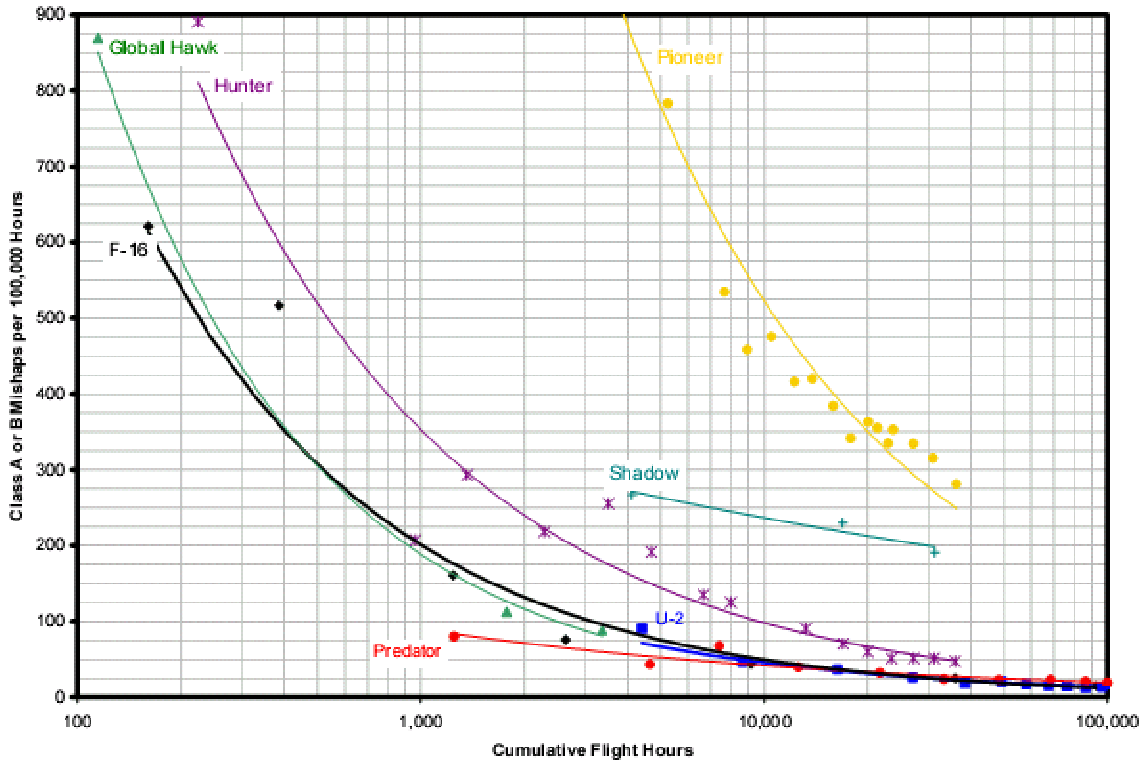

Figure 14. Mishap rate comparison (DoD, 2005)

An additional approach is the vulnerability of UAVs in combat situations. Many of the current UAVs are vulnerable to different air defense systems, which of course depends on the altitude and the speed of the UAV. Certainly this applies to tactical UAVs up to Medium-Altitude, Long-Endurance (MALE) UAVs like the Predator. Anti-aircraft artillery (AAA), shoulder-fired man portable systems (MANPADS), and radar directed low medium and high altitude surface to air missiles can all be quite lethal to UAVs within their range. Currently the concept of operations calls for air superiority and the elimination of the air defense threats before a UAV is sent into this area. In the future, the concept of operations could be extended if active countermeasures were installed on UAVs, which would enable their mission to be extended to surveillance prior to a conflict.

C. UAV SYSTEM EXAMPLE: PREDATOR

Smaller in size compared to its larger brother Global Hawk, the 27-foot-long UAV Predator is much cheaper, $4.5 million each. As a result, it may be worth the risk of being sighted and shot-down to fly a Predator at relatively low altitudes (25,000 feet and below).

Predators were first deployed for reconnaissance and surveillance operations by the US military during the 1995 civil war in Bosnia. They are now far more extensively used by the USAF in the operations such as Afghanistan.

The Predator is a medium-altitude, long-endurance remotely piloted aircraft. Its primary mission is interdiction and conducting armed reconnaissance against critical, perishable targets. When it is not actively pursuing its primary mission, it acts as the Joint Forces Air Component Commander-owned theater asset for reconnaissance, surveillance and target acquisition in support of the Joint Forces Commander.

The basic crew is one air vehicle operator (AVO) or pilot and two sensor operators. They fly the aircraft from inside the ground control station via a line-of-sight data link or a satellite data link for beyond line-of-sight flight (see Figure 15).

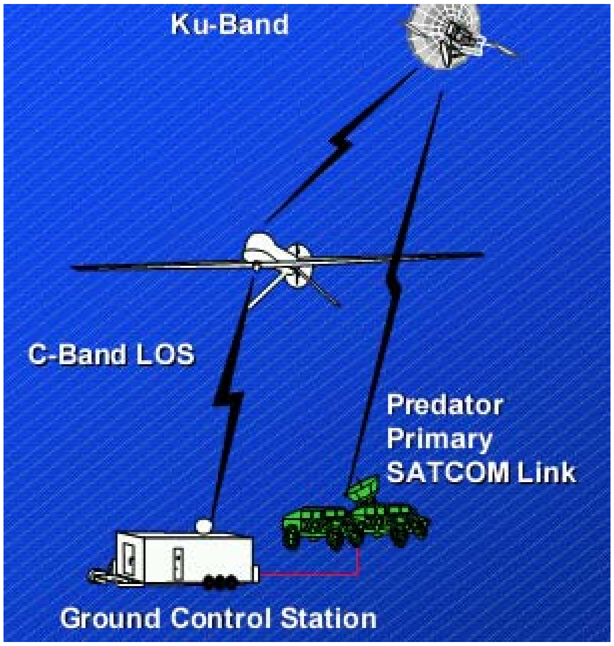

Figure 15. Data and satellite link of the Predator (Cooter, 2001)

The Predator is equipped with a color camera in the nose (generally used by the pilot for flight control), a day variable-aperture TV camera, a variable-aperture infrared (IR) camera (for low light/night), and a synthetic aperture radar (SAR) for looking through smoke, clouds or haze. The cameras produce full motion video while the SAR produces still-frame radar images. Thus, it can produce near-real-time multi-sensor imagery and intelligence. The latest development of the RQ/MQ-1 is equipped with lasers, targeting systems, and a pair of hellfire missiles. The following model "MQ-9 is intended to fly higher and faster, provide more power, and carry larger payloads than the original Predator system. It is intended to provide a more robust airframe, using a conventional turbo-prop engine and redundant avionics. MQ-9 will be used primarily in an armed reconnaissance ("hunter-killer") role and will perform reconnaissance, surveillance, and target acquisition (RSTA) as a secondary role" (Christie, 2003).

One has to understand the Predator as a complex system which includes

- 4 x Air Vehicles

Figure 16. UAV Predator (Cooter, 2001)

- 1 x Ground Control Station

Figure 17. Predator Ground Control Station – outside (Cooter, 2001)

Figure 18. Predator Ground Control Station – inside (Cooter, 2001)

- 1 x Predator Primary SATCOM Link

Figure 19. Predator Primary SATCOM Link (Cooter, 2001)

For operating the Predator a HUD is being used. Figure 20 shows the current one which will be replaced in the future by a more advanced IHUD (see Figure 21).

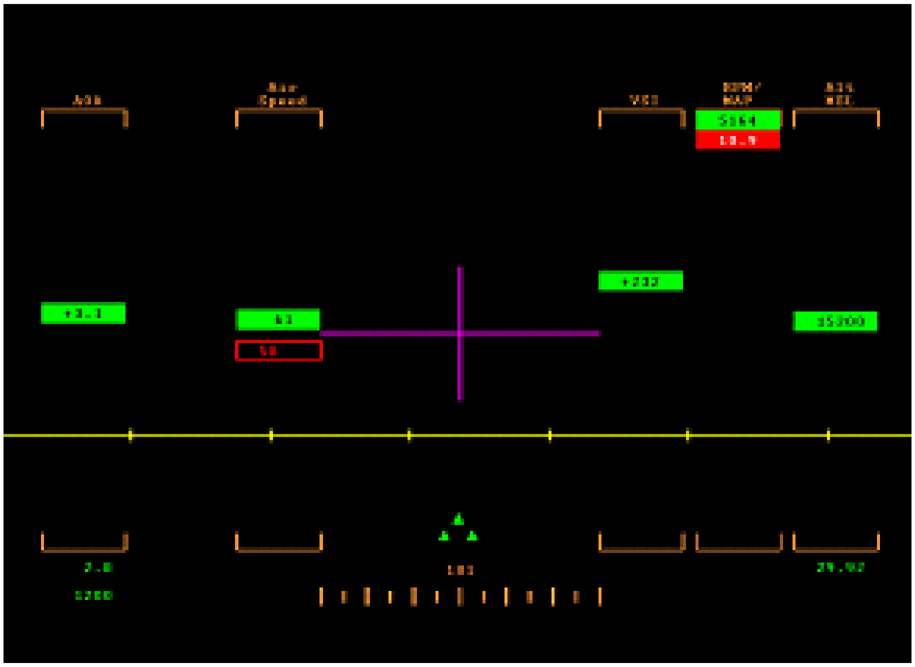

Figure 20. Heads-Up-Display Predator (Ball et al., 2002)

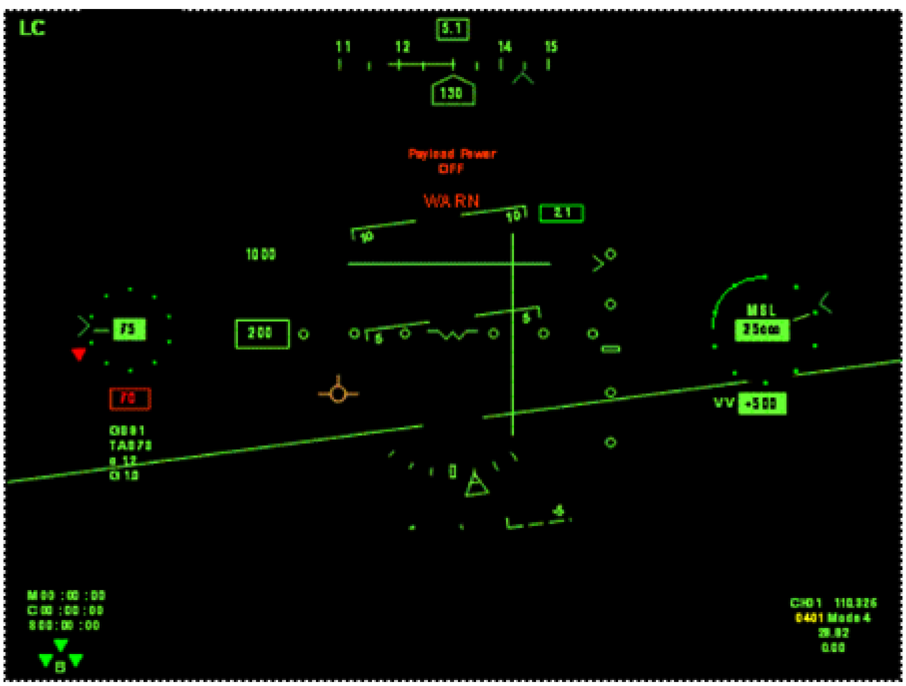

Figure 21. Heads-Up-Display Predator – IHUD (Guy, 2007c)

The Predator HUD can be considered as one of the traditional flight instruments which we want to compare with the new prototype display design in the present research.

Next to the HUD/ IHUD the pilot uses the front color camera for operating the Predator (see Figure 22 and Figure 23).

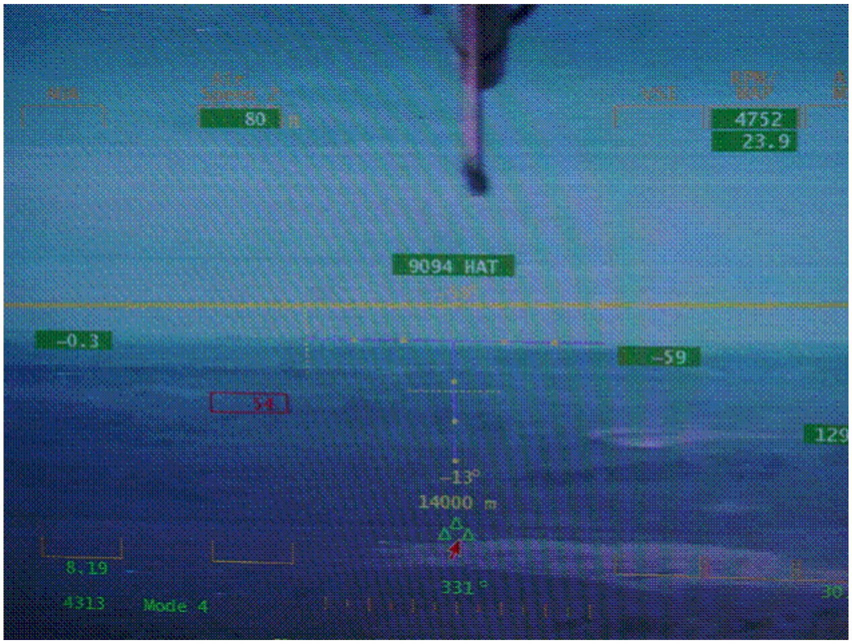

Figure 22. View from the color camera in the nose of the Predator (Guy, 2007b)

Figure 23. View from the color camera in the nose of the Predator during recovery (Guy, 2007b)

D. GROUND CONTROL STATION

The ground control station (GCS) is the control center of any UAV system. The main tasks that have to be accomplished are data processing of the incoming data and sending control signals to the UAV. Thus three main features will be executed in the GCS:

- Mission planning: The purpose of mission planning is to analyze available information and develop a flight plan. This involves identifying and prioritizing targets, and examining sensor capabilities relative to the chosen targets. Weather analysis also is common.
- Mission control: Mission control is responsible when the aircraft is on the ground, when it is getting launched, and during the mission, for the navigation and possible mid-flight rerouting. It is also responsible for monitoring and controlling of any payload, and for recovering the aircraft if an unusual attitude occurs.
- Data manipulation: Data manipulation is responsible for processing, exploiting, and archiving of data during the flight and / or after the flight (Anderson, 2002).

The Predator GCS provides command and control of the air vehicle through the pilot station using stick and rudder control. The sensor operators monitor the flow of information from the UAV. Their sources of information are the TV camera, the infrared camera, and the onboard radar. Depending on the weather conditions, advantageously the radar can be operated simultaneously with either the TV camera or the infrared camera. For communication purposes, a C-band line-of-sight data link and for beyond-line-of-sight a Ku-band satellite data link are used (Anderson, 2002).

The following pictures give an idea about the inside of a GCS. For comparison reasons, not only the GCS of the Predator will be displayed, but also several others.

Figure 24. GCS Predator - Inside view (Cooter, 2006)

Figure 25. GCS Predator - Inside view

Figure 26. GCS Predator - Inside view (Cooter, 2006)

Figure 27. GCS Pioneer – Inside view

Figure 28. GCS Hunter – Inside view

Figure 29. GCS of German System KZO – Inside view

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V. METHOD

A. METHODOLOGY

1. Experiment Goals and Purpose

The goals of this study are to evaluate the strengths and weaknesses of a new proposed display design, called the WEBER-Box, compared to the traditional flight instruments.

2. Research Questions

The study is limited in its scope and assets. We wanted to answer the following questions:

a) Will the new display design help the pilot to recognize the current aircraft attitude?

b) Will the new display design help the pilot to differentiate between a usual and unusual attitude?

c) Will the new design help to prevent misperception of an unusual attitude when the UAV is not in an unusual attitude?

Answers to these questions reveal whether the new display design helps to

- recognize the current attitude at least as well as the traditional display design,
- differentiate between a usual and an unusual attitude at least as well as the traditional design, and
- determine whether the new design prevents misjudging an unusual attitude.

3. Constraints and Assumptions

Since the experiment involved human participants, the plan for the experiment was submitted to the Institutional Review Board, which approved the experiment (see Appendix C).

The major constraint was the use of a digital hand stopwatch, type SPORTLINE®. Therefore the accuracy of measuring the time to judge the current attitude may have been decreased, but this possible disadvantage was constant across conditions and, presumably across data points (1,120).

The major assumption was about the definition of unusual attitude. According to Air Force Instruction 11-217 “an unusual attitude is an aircraft attitude occurring inadvertently”. Since this is very broad, we followed a definition according to industry …”as one where pitch unintentionally exceeds 25 degrees nose up or 10 degrees nose down, bank angle unintentionally exceeds 45 degrees, and the airspeed is inappropriate for the conditions” (Guy, 2007a).

4. Technical Equipment

The experiment took place at the Naval Postgraduate School, Monterey, California, Watkins Building, room 212B.

Two workstations were used. Workstation one was for instruction and training while workstation two was established for the underlying experiment.

Workstation one:

The computer-generated images were displayed on a 19” computer monitor with a 1024 x 768 pixel resolution. The pictures of the flight situations were generated by screenshots of the commercial flight simulator software X-Plane™, version 7.13 and version 8.40 and by screenshots of the WEBER-Box program, respectively. The pictures were stored in a PowerPoint™ slideshow (see Appendix D) to ensure that every participant saw the different attitudes in the same order.

Workstation two:

The computer-generated images were displayed on a 19” computer monitors with a 1024 x 768 pixel resolution. The second screen was located on top of each other similar to the ground station of a Predator. It provided during the duration of the experiment the definition of unusual attitude.

The simulation of the flight situations were generated by the commercial flight simulator software X-Plane™, version 7.13 and version 8.40 and by the WEBER-Box program, respectively. The predefined simulations of usual and unusual attitude will be stored in Camtasia Studio™ from TechSmith to ensure that every participant saw exactly the same the different attitudes in his randomly assigned order.

5. Data Collection Methodology

Several types of data were collected during the experiment.

First, demographic data were collected by a pre-experiment questionnaire. Secondly data were collected during the experiment. These were data for correct/ incorrect responses, and the measured time each participant needed to judge the current attitude. In addition, the use of subjective self-assessment provided a scale of five judgments in every questionnaire.

In summary, a "repeated measures" design was used in which all the participants were exposed to all the instrument setups and all the sub-experiments. The order of presentation of the two displays and the color-coding was pseudo-randomized (see Appendix J and K). This procedure ensured that learning effects would be counterbalanced over the experiment.

6. Data Analysis Methodology

The data was hand recorded by using a template (see Appendix K). The participant judged the current attitude and responded by saying "Usual attitude" or "Unusual attitude". The experimenter measured the time and transferred the time into the template together with the participants' verbal response of his judgment.

The data then were analyzed by commercial software Excel 2003 and SPSS 13.0 for Windows. Methods that have been used were Analysis of Variance and the paired t-test. The statistical analysis concentrated on the differences between the measurements depending on the experimental condition: display type (traditional or WEBER-Box) and color coding (none or yellow).

Two questionnaires were handed out. The pre-experiment questionnaire provided demographic information and, for pilots, aviation background. The post-experiment questionnaire was helpful as a secondary method for determining the effects of the different variables display design and color/ no color, and to analyze the relationship between subjective and quantitative data.

B. EXPERIMENTAL DESIGN

1. Basic Experimental Design

The experiment was designed to compare the correct responses of the judgment of usual or unusual attitude while changing the variables display design and color coding or not. Therefore, it was a randomized "within subjects" design because every participant received the same treatment. Since two groups, pilots and non-pilots, were involved in the experiment, their comparison was "between subjects."

The dependent variables were the outcome of correct response and the time a participant needed to judge the attitude. Independent variables were the display design and the factor color or no color.

Each participant was told at the beginning that his duty station is the ground control station of a Predator.

2. Experimental Procedure

The overall experiment was subdivided into four phases.

Phase one – Pre-Paperwork:

The participant filled out the necessary paperwork, including a consent form, a privacy act statement, a minimal-risk information form, and an initial/ demographic questionnaire.

Phase two – Introduction and Training

Then the participant was introduced to the experiment. In a PowerPoint presentation he received information about the UAV, his task as an operator of the UAV, and details about usual and unusual attitude since this was the key part of the underlying experiment. The participant also watched a 2-minute video of the work as an operator in the ground control station of the Predator.

This pre-experimental part, phases one and two, took approximately 25 minutes.

Phase three – Experiment

After completion of introduction and training, the participant started with the first experimental sub-task, given a particular simulation setup, that is, with or without the new instrument. Each of the 14 trials of the sub-experiment was scheduled for 10 seconds. Two monitors were placed on top of each other to create an environment like a ground station of a UAV. The top monitor was only used for displaying the definition of unsual attitude. The first two trials in each combination always were practice trials.

The experimenter started the prepared simulation of 19 different flight simulations that ended in a usual or unusual attitude. Each simulation appeared for ten seconds. This was also the amount of time given to the participant to judge the attitude. After ten seconds, the next attitude appeared automatically. One half of the trails were created as usual attitude while the other half as unusual attitude.

After accomplishing the first two blocks of trials, the participant was allowed a 5-minute break if desired.

Then the participant started the second sub-experimental task.

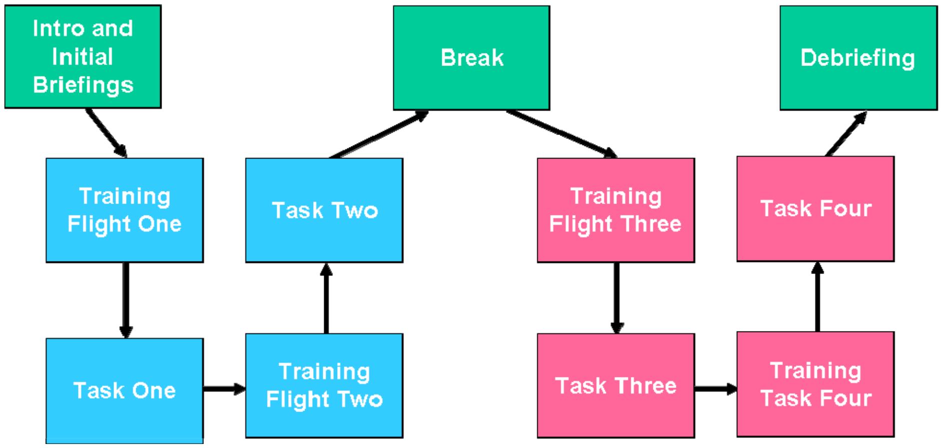

Figure 30. Experimental setup

In summary, all the participants were exposed to all the instrument setups and all the sub-experiments. Each participant was confronted with seven trails of usual attitude with traditional design and seven trails of unusual attitude with the traditional design and, likewise with the new design (see Figure 30).

Phase four – Post-Paperwork

When finished, the participant was asked to fill out the post-experimental questionnaire and support the experiment with his suggestions and comments. This completed the experimental session.

C. PILOT STUDY ONE

The first pilot study was conducted with three participants to test the procedures, apparatus, and tasks. The setup of this pilot study differed from the later conducted experiment. It was a dynamic environment with a flight simulation that stopped after 120 seconds and the participant had to judge the current attitude. For this judgment he was given ten seconds. There was also only the comparison between the traditional display design without color coding and the new display design with color coding. Two of the three participants claimed that this was a disadvantageous setup due to the outstanding support the new display design received. The recommendations were to extend the setup and provide both of the display design types with color and compare the results.

D. PILOT STUDY TWO

Therefore another pilot study had to be conducted according to the above mentioned recommendations. Again three participants tested the procedures, apparatus, and tasks. The new setup contained now both display designs, each with and without color coding. We also changed the settings contrary to the former pilot study to a static environment with a presentation mode where the participant had to judge the attitude in a maximum time of ten seconds. If he was unable to judge in this period, it was counted as incorrect. All of the participants were tested on each of the four combinations. The pilot study demonstrated that every participant was able to judge the current attitude and the given time of ten seconds sufficed.

E. PARTICIPANTS

The participants were randomly assigned on a volunteer basis from students and faculty of NPS. The study involved 20 participants, evenly partitioned into ten pilots and ten non-pilots. Eight of the pilots were jet pilots and two were helicopter pilots with an average of 1,348 flight hours. Therefore the group of pilots can be considered as participants with a strong aviation background and a high flight experience. The mean age of the pilots was 36 in the range from 28 to 42. The mean age of the non-pilots was 34 with a range from 28 to 42.

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VI. DATA ANALYSIS

A. HYPOTHESIS

Inferential testing techniques enable the researcher to decide between the null hypothesis and the alternative hypothesis. Devore, 2004, defines the null hypothesis, "denoted by α , as the claim that is initially assumed to be true." The alternative or secondary hypothesis, "denoted by H_a, is the assertion that is contradictory to H_0. The null hypothesis will be rejected in favour of the alternative hypothesis only if sample evidence suggests that H_0 is false. If the sample does not strongly contradict H_0, we will continue to accept the null hypothesis. The two possible conclusions from a hypothesis-testing analysis are then *reject* H_0 or *fail to reject* H_0" (Devore, 2004).

A test procedure is specified by the following:

- A test statistic, a function of the sample data on which the decision (reject H_0 or do not reject H_0) is to be based.
- A rejection region, the set of all statistic values for which H_0 will be rejected.

The null hypothesis H_0 will then be rejected if and only if the observed or computed test statistic value falls in the rejection region (Devore, 2004). Evidence to reject a null hypothesis H_0 is given if the p-value is small enough (the probability that a difference of the magnitude observed may have occurred by chance).

Since we were testing two different measures of effectiveness (MOE), two different null hypotheses were stated along with their corresponding alternative hypothesis. Our dependent variables, or MOEs, were the "probability of correct response" and its corresponding "time of response".

1. MOE "Probability of Correct Response"

a. Null Hypothesis

H_0: no difference between traditional and prototype display design *b.* ***Alternative Hypothesis***

H_a: prototype display design provides a higher percentage of correct response

Null or alternative hypotheses can be explored by using the results of the binary data (1 for correct response and 0 for incorrect response) of the experiment when the test participant had to judge the current attitude.

2. MOE "Time of Response"

a. ***Null Hypothesis***

H_0: no difference in response time between traditional and prototype display design

b. ***Alternative Hypothesis***

H_a: prototype display enables to respond correctly in a shorter time

The second null or alternative hypotheses can be explored by using the results of the time measurement in seconds and milliseconds of each judgement task. The time each participant required to judge his attitude, indicates how fast he can build his model of the current spatial situation and therefore being able to start a recovery if necessary. Each participant is tested on the traditional and the prototype display design. The order of presentation was counterbalanced. The data provides an indication about which display design enables a person to assess an aircraft attitude more rapidly.

In addition, the post-experiment questionnaire provides us with feedback for both measures of effectiveness. Assuming a faster response to the judgement task when using the prototype display design, this should be reflected by selecting an answer of "border line", "somewhat more" or "much more" with regards to better awareness of spatial orientation.

Additionally, an answer to the question of the influence of a color coded support for pitch and/ or roll, either for the traditional or the prototype display design, can be extracted from the questionnaire. By choosing any answer above “border line”, we can assume that the participant favoured an additional color support.

3. Baseline Determination

Before starting with any experiment, it is necessary to evaluate the number of participants necessary to achieve a statistically significant outcome.

Kanji (1999) provides a general overview of the relation between a true or false hypothesis and when to reject or not to reject this hypothesis. The two ways of making mistakes when performing a hypothesis test are type I and type II errors. Type I errors represent mistakenly rejecting H_0, when H_0 is true. On the other hand, an error of type II occurs when H_0 is false and it is not rejected.

The goal is to avoid type I and type II errors and make the correct decision about accepting or rejecting the null hypothesis.

What is true in the population?

		Treatments have no effect	Treatments have an effect
Conclusion reached in a study	No effect	**Correct decision** (p = 1 – β)	**Type II error** (p = t^*_{n-1})
	Treatment effect	**Type I error** (p = α)	**Correct decision** (p = 1 – β)

Power

Table 2. Outcomes of statistical tests (Murphy & Myors, 2004)

The power of a statistical test is defined as the probability of rejecting the null hypothesis, H_0, when the alternative hypothesis is true (Montgomery & Runger, 2007).

Instead of simply calculating the level of power, it is also possible to determine the sample size to achieve specific levels of power. By convention, it is necessary to achieve at least a power of 0.05, otherwise the probability is greater than .05 that a Type I error will occur, i.e., failing to reject H_0 when H_0 is false. Achieving a power greater than 0.08 is always desirable (Murphy & Myors, 2004).

We used a power analysis and determination of the sample size according to DeVeaux et al., 2005. By regrouping the formula

$$ME = t^*_{n-1} \cdot \frac{s}{\sqrt{n}}$$

from: $$\sqrt{n} = \frac{t^*_{n-1} \cdot s}{ME}$$

to: $$n = \left(\frac{t^*_{n-1} \cdot s}{ME} \right)^2$$

it is possible to determine the sample size.

Explanation: ME: margin of error

extent of an interval on either side

t^*_{n-1}: confidence interval

an interval estimate for a population parameter

s: standard error

estimate of the standard deviation of a sampling distribution

calculated by the product of p x q with p as the probability that the observed statistic value could occur and q as the probability that the observed statistic value could not occur

To determine an appropriate sample size, we made the following assumptions. The level of significance will be α = 0.05 and the probability of 90% that the statistic value will occur. The results shown in Table 2 were calculated by using the above displayed formula in a spreadsheet in Microsoft Excel 2003.

ME	P	Q	Z	Sample size n	CI
0.03	0.9	0.1	1.282	14.79	**80%**
0.04	0.9	0.1	1.645	13.70	**90%**
0.04	0.9	0.1	1.96	19.45	**95%**
0.05	0.9	0.1	2.326	17.53	**98%**
0.05	0.9	0.1	2.576	21.50	**99%**

Table 3. Number of proposed participants

Therefore we designed the experiment for 20 participants, assuming a margin of error of 0.04 with a p-value of 90% using a confidence interval of 95%. Since we decided to choose a level of significance of α = 0.05, H_0 can be rejected if the p-value is less than 0.05.

B. GENERAL DATA ANALYSIS

1. General Data Description

During the experiment 1,120 data points (20 participants x 4 trial x 14 tests = 1,120) in different categories were collected. The following software was used for the data analysis: Microsoft Excel 2003 and SPSS 13.0 for Windows. These programs have also been used for the graphical output of the analysis.

The data categories were:

1) Initial Questionnaire: The questionnaire was also used to obtain demographic data like age in years and flight experience in hours.

2) Judgement of the current attitude: The answer to the task of judging the current attitude as correct or incorrect.

3) Judgement Time: The time the participant needed to judge the current attitude in sec.

2) Post Experiment Questionnaire: The subjective assessment of the experiment.

2. Demographic Data

a. Age

Both pilots and non-pilots had a similar mean age. The standard deviation of the non-pilots was a little higher due to more participants of 40 years and older. The detailed statistics are displayed in Table 4.

	Mean	STD	Minimum	Maximum
Pilots	35.50	3.85	28	42
Non-pilots	34.00	4.77	28	42
Total	34.75	4.40	28	42

Table 4. Statistics on participants' age

b. Flight Experience

ID-Participant	Pilot (1 / 0)	Flight-Hours	Mean Flight-Hours	STD
001	1	80.00		
002	1	20.00		
003	1	2000.00		
004	1	2500.00		
005	1	1400.00		
006	1	2400.00		
007	1	10.00		
008	1	1971.00		
101	1	2000.00		
102	1	1100.00	1348.10	943.29

Table 5. Flight-Hours – Raw data

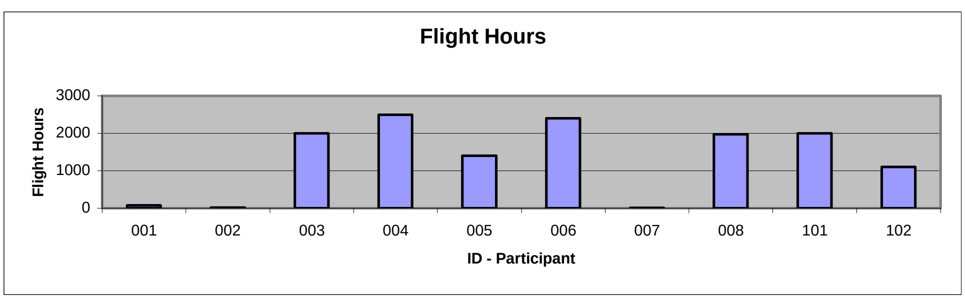


Figure 31. Chart of individual flight-hours

Seven pilots out of the total of ten pilots had more than 1,000 flight hours and four out of these seven pilots had more than 2,000 flight hours, with one participant very close to the 2,000 flight hour barrier, one can consider the group of pilots as experienced. Most of them had some experience with SD during their flying career. Table 6 provides the descriptive statistics of the pilot's flight experience.

	Mean	**STD**	**Minimum**	**Maximum**
Flight experience	1,348.10	943.29	10	2,500

Table 6. Statistics on pilot's flight experience

3. General Statistical Methodology

We tested each participant on the factors "display design" and "color support/ no color support." In addition, there were two types of participants, pilots and non-pilots, yielding a full factorial design with $2^3 = 8$ factor-level combinations. Our measures of effectiveness were correct answer of aircraft attitude (usual or unusual attitude) and the time a participant needed to make that judgment (see Figure 32 and Figure 33).

Analysis of variance (ANOVA) was used to test the effects of the independent variables on the correct judgment of attitude and the time to respond.

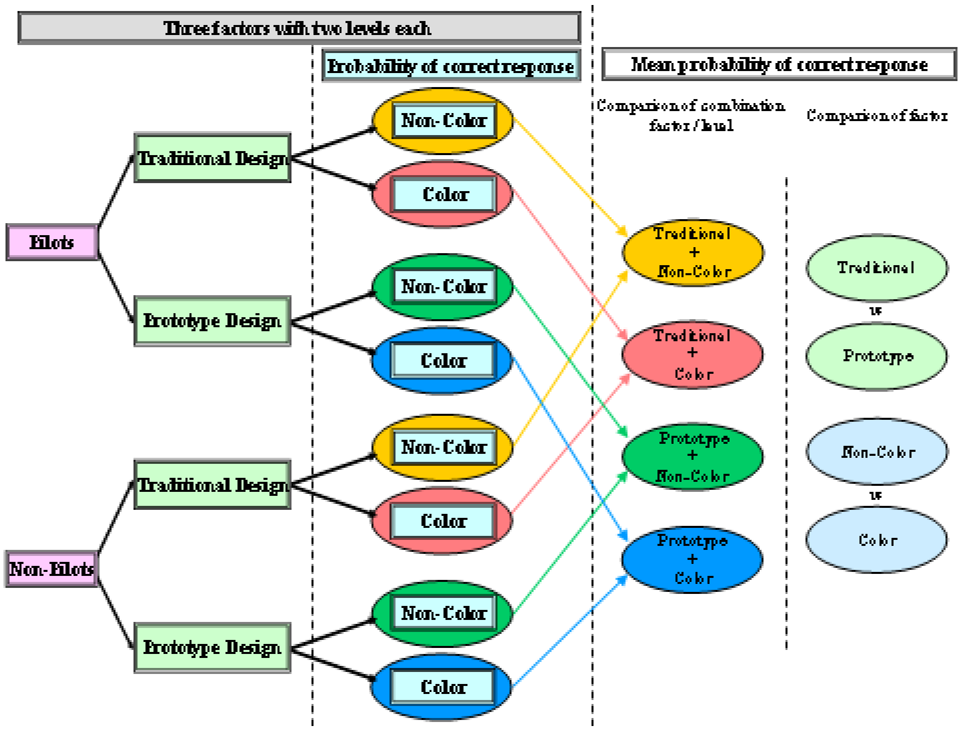


Figure 32. Combination and evaluation of correct response

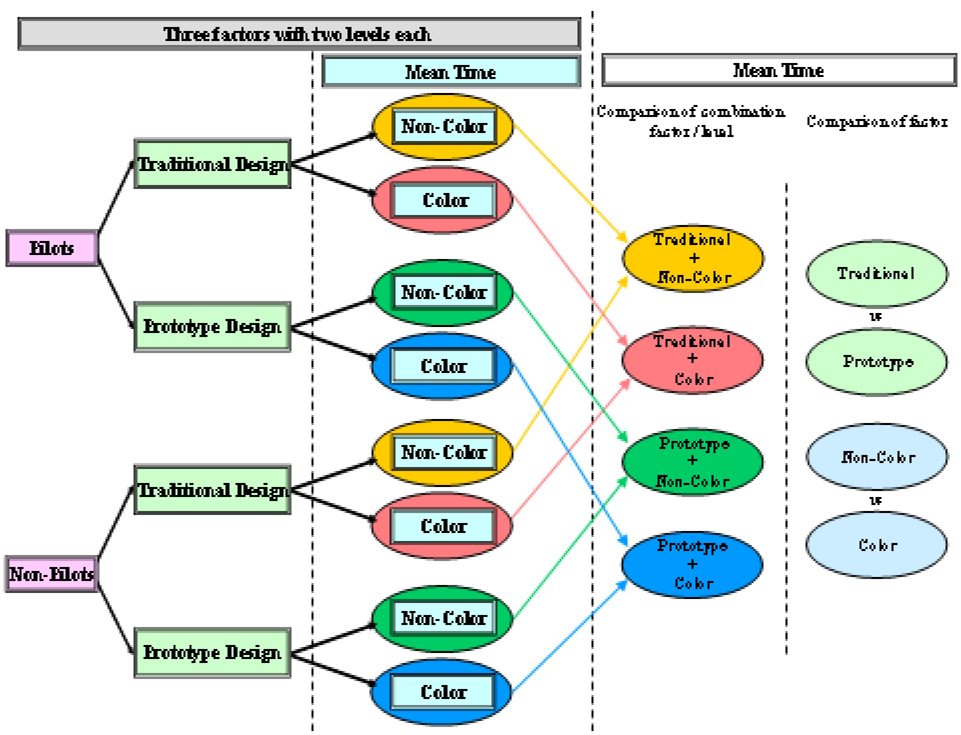


Figure 33. Combination and evaluation of time to judge

4. Baseline Comparison

The basic data are displayed in the middle section of Figure 32 and Figure 33 and combined in Table 7 with the raw data.

ID-Participant	Pilot (1 / 0)	prob. correct response (Traditional + Non-Color)	mean time (Traditional + Non-Color)	prob. correct response (Traditional + Color)	mean time (Traditional + Color)	prob. correct response (Prototype + Non-Color)	mean time (Prototype + Non-Color)	prob. correct response (Prototype + Color)	mean time (Prototype + Color)
001	1	1.00	1.44	1.00	0.66	0.93	0.91	1.00	0.68
002	1	0.57	3.07	1.00	1.28	1.00	2.22	1.00	1.31
003	1	0.86	1.74	0.79	2.32	1.00	1.54	1.00	1.45
004	1	1.00	1.68	1.00	1.19	1.00	1.06	1.00	1.80
005	1	0.86	2.02	1.00	0.77	1.00	1.30	1.00	0.72
006	1	0.93	1.91	1.00	1.77	1.00	1.05	1.00	1.15
007	1	0.86	1.44	1.00	1.63	1.00	1.07	1.00	1.03
008	1	1.00	1.70	1.00	1.74	1.00	1.93	1.00	1.20
101	1	1.00	1.62	1.00	2.28	1.00	1.40	1.00	0.89
102	1	1.00	2.29	1.00	2.02	1.00	2.00	1.00	1.36
201	0	1.00	2.31	1.00	1.74	1.00	1.83	1.00	1.04
202	0	0.93	1.46	0.86	1.88	0.93	1.25	1.00	0.83
203	0	0.86	2.02	1.00	0.88	1.00	1.57	1.00	0.96
204	0	0.86	2.22	0.93	1.22	0.86	1.79	1.00	0.84
205	0	1.00	3.06	1.00	3.27	1.00	2.20	1.00	1.84
206	0	0.71	4.89	1.00	0.98	1.00	1.74	1.00	1.19
207	0	0.93	2.40	1.00	1.10	1.00	1.83	1.00	0.79
208	0	0.86	3.02	1.00	0.96	1.00	1.38	1.00	0.89
209	0	1.00	2.83	1.00	1.03	1.00	2.21	1.00	0.90
210	0	0.86	3.85	1.00	1.03	0.93	2.19	1.00	0.91
	MEAN:	0.90	2.35	0.98	1.49	0.98	1.62	1.00	1.09
	STD:	0.11	0.87	0.05	0.63	0.04	0.42	0.00	0.32

Table 7. Baseline comparison – Raw data

C. ANALYSIS OF VARIANCE

1. General Linear Model

Analysis of variance (ANOVA) is an analysis method for testing equality of means across three or more treatment groups. In our case we used a one-way ANOVA for repeated measures. On one hand we have a "within subjects" (see Table 8 and Table 9) design because every participant received the same treatment.

Within-Subjects Factors

Measure: MEASURE_1

display	color	Dependent Variable
1	1	prob. correctresponse Traditional NonColor
	2	prob. correctresponse Traditional Color
2	1	prob. correctresponse Prototype NonColor
	2	prob. correctresponse Prototype Color

Table 8. Within subjects for probability of correct response

Within-Subjects Factors

Measure: MEASURE_1

display	color	Dependent Variable
1	1	meantime Traditional NonColor
	2	meantime Traditional Color
2	1	meantime Prototype NonColor
	2	meantime Prototype Color

Table 9. Within subjects for mean time

The two groups of participants, pilots and non-pilots, were a “between subjects” factor (see Table 10).

Between-Subjects Factors

		N
Pilot (1 / 0)	0	10
	1	10

Table 10. Between subjects

Therefore we are able to assess the effect of display design or color versus the status as pilot or non-pilot.

2. ANOVA for Probability of Correct Response

The ANOVA for probability of correct response gave us the statistical output shown in Table 11.

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	display	color	Type III Sum of Squares	df	Mean Square	F	Sig.
display	Linear		.049	1	.049	11.130	.004
display * Pilot10	Linear		.000	1	.000	.056	.816
Error(display)	Linear		.079	18	.004		
color		Linear	.042	1	.042	10.805	.004
color * Pilot10		Linear	.001	1	.001	.250	.623
Error(color)		Linear	.071	18	.004		
display * color	Linear	Linear	.016	1	.016	3.540	.076
display * color * Pilot10	Linear	Linear	.000	1	.000	.053	.820
Error(display*color)	Linear	Linear	.083	18	.005		

Table 11. Test of within-subjects contrasts for probability of correct response

The effect of display design (traditional or Weber Box) was highly significant, F = 11.13, p = 0.004. Likewise, the effect of color coding was significant, F = 10.81, p = .004. There were no significant two-way interactions between display design and color (p = 0.076), display design and pilot/ no pilot (p = 0.816), or color and pilot/ no pilot (p = 0.623). Similarly, the three way interaction between display, color, and pilot was not significant (p = 0.820). Figure 34 shows the nearly-significant interaction between display type and color. It can also be seen in the figure that response accuracy was higher for the WEBER Box than for the traditional display, both with and without color.

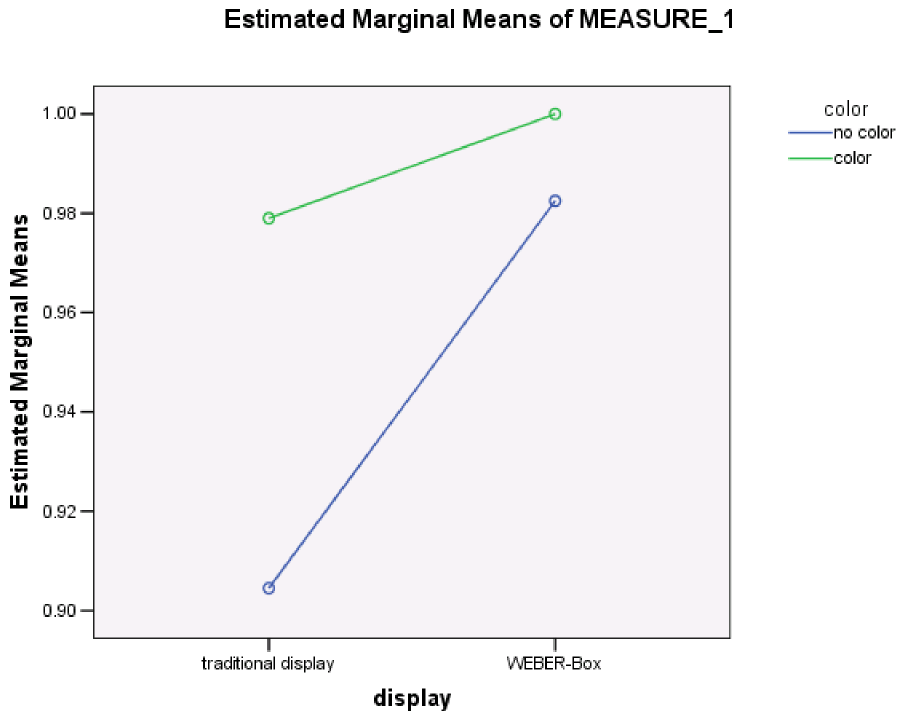


Figure 34. Interactions of display design and color

Participants using the WEBER-Box reached a probability of correct response of 98% without color coding and 100% with color coding. These results indicate that high accuracy in judging attitude is achieved using the WEBER Box.

a. T-Test: Traditional Design Versus Color

In support of the ANOVA findings, a *t*-test was performed to determine whether color coding had an effect on response accuracy with the traditional display (see Table 12). The significant result, $p < .05$, indicates that response accuracy using the traditional display was better with color coding than without it. The boxplot also supports this conclusion (see Figure 35).

	prob. correct response (Traditional without color)	prob. correct response (Traditional with color)
Mean	0.9045	0.979
Variance	0.012552368	0.003146316
Observations	20	20
P(T<=t) one-tail	0.005702026	
P(T<=t) two-tail	0.011404052	

Table 12. Analysis in the probability of correct response between traditional design without color vs. with color

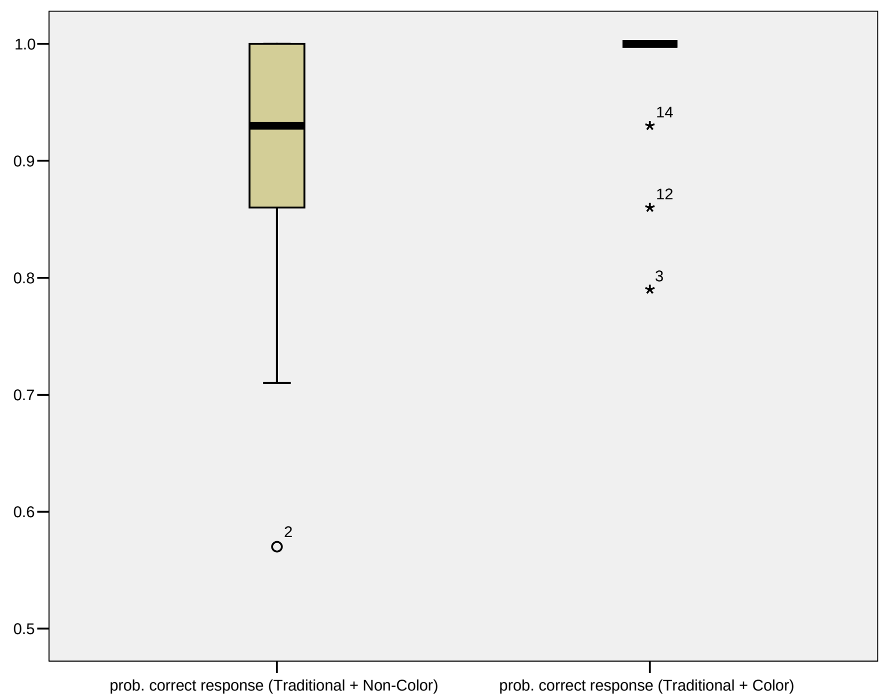


Figure 35. Graphical output of the analysis in the probability of correct response between traditional design without color vs. with color

3. ANOVA for Response Time

The ANOVA for response time resulted in the statistical output shown in Table 13.

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	display	color	Type III Sum of Squares	df	Mean Square	F	Sig.
display	Linear		6.311	1	6.311	58.699	.000
display * Pilot10	Linear		.374	1	.374	3.479	.079
Error(display)	Linear		1.935	18	.108		
color		Linear	9.737	1	9.737	23.978	.000
color * Pilot10		Linear	3.054	1	3.054	7.520	.013
Error(color)		Linear	7.310	18	.406		
display * color	Linear	Linear	.533	1	.533	1.951	.179
display * color * Pilot10	Linear	Linear	.422	1	.422	1.544	.230
Error(display*color)	Linear	Linear	4.918	18	.273		

Table 13. Test of within-subjects contrasts for mean response time

Display type (traditional versus WEBER Box) had a highly significant effect on mean response time, $F = 58.70$, $p < 001$. Similarly, color coding had a highly significant effect on response time, $F = 23.98$, $p < .001$.

The two way interaction of display type and pilot/ non-pilot did not reach significance, $F = 3.48$, $p = .079$, nor did the interaction of display type and color coding, $F = 1.95$, $p = .179$. On the other hand, the interaction of color coding and pilot/ non-pilot was significant, $F = 7.52$, $p < .05$. The three way interaction of display type, color coding, and pilot was not significant, $F = 1.54$, $p = .230$.

A graphical representation of display type and color coding is given in Figure 36. It can be seen in the figure that response times were shorter with the new display design (WEBER Box) than with the traditional instrument design, and that held true for both color coded and no color coded displays.

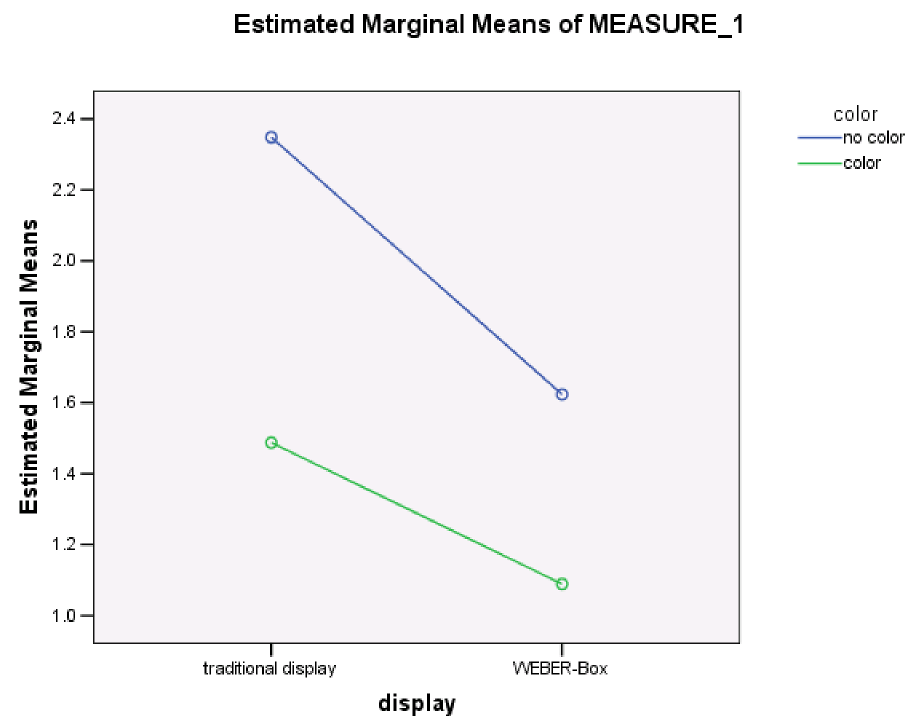


Figure 36. Non-significant interaction between display design and color

The mean time decreased when switching from the traditional display to the WEBER-Box. Adding color to the displays made this decrease even more obvious.

Figure 37 shows the significant interaction between display design and pilot/ non-pilot. Both pilots and non-pilots responded more quickly with the WEBER Box than with the traditional instrument design, but the advantage of the WEBER Box was greater for the non-pilots. This result is not surprising because pilots have considerable experience with the traditional display design, whereas the non-pilots were quite slow in responding to the traditional display.

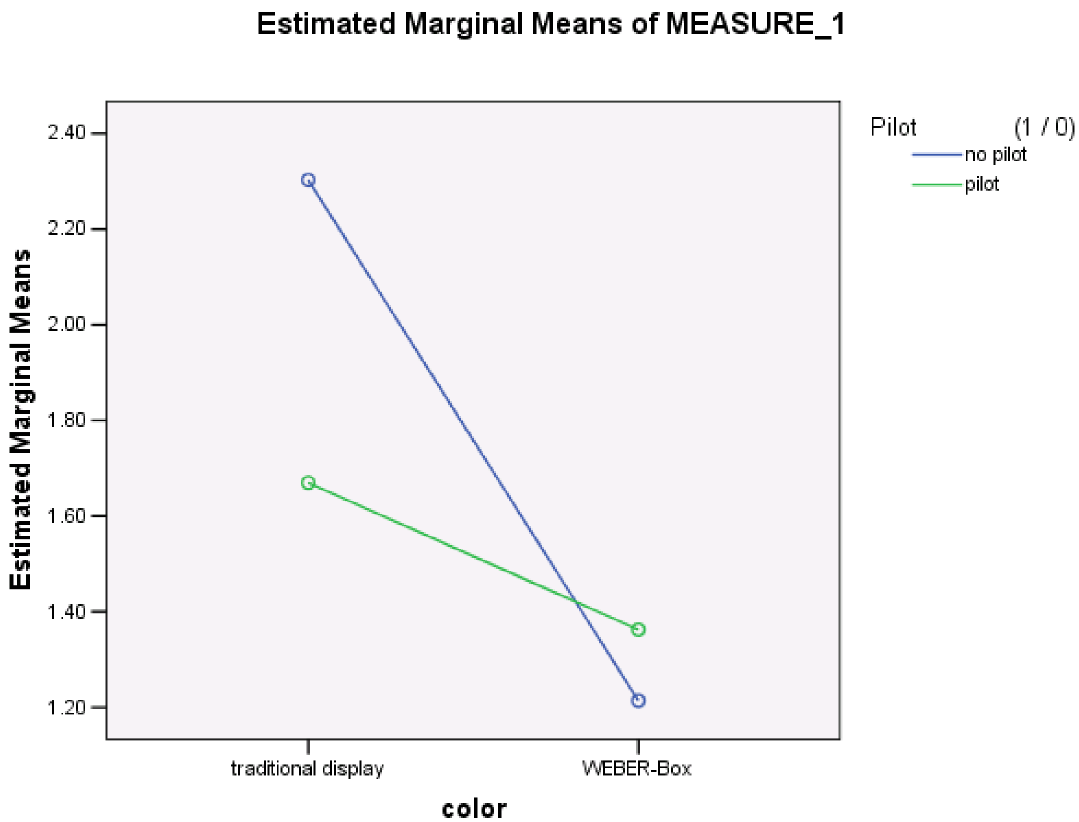


Figure 37. Interactions between color and pilots

This graphical outcome shows at once that the non-pilots profited most from the WEBER-Box. Both, pilots and non-pilots, could decrease their mean response time when tested on the WEBER-Box. But the non-pilots mean response time dropped in such a significant way even underneath the pilots value when using the WEBER-Box.

This is an additional proof of the superiority of the WEBER-Box. On the other hand there is room fur further investigations, why the pilots didn't benefit as much from the WEBER-Box as the non-pilots.

a. T-Test: Pilot Versus Display Design

In support of the ANOVA findings a *t*-test was performed to determine whether display design had an effect for mean response time on pilots (see Table 14). The significant result, $p < .05$, indicates that the mean response time of the pilots using the WEBER-Box was better than with the traditional design. The boxplot also supports this conclusion (see Figure 38).

	mean time (Pilot with trad. design)	***mean time (Pilot with WEBER-Box)***
Mean	1.729	1.329
Variance	0.136054444	0.123676667
Observations	10	10
P(T<=t) one-tail	0.011579295	
P(T<=t) two-tail	0.023158589	

Table 14. Analysis of the response time between pilots with the traditional design vs. the WEBER-Box

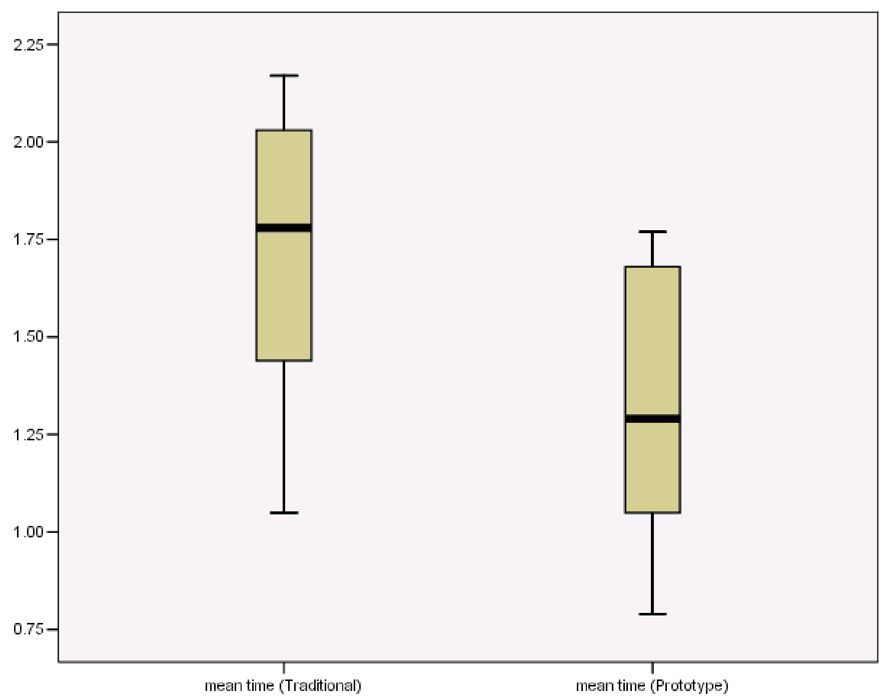


Figure 38. Graphical output of the analysis of the mean response time for pilots with the traditional design vs. the WEBER-Box

In support of the ANOVA findings another *t*-test was performed to determine whether display design had an effect for mean response time for non-pilots (see Table

15). The significant result, $p < .05$, indicates that the mean response time of the non-pilots using the WEBER-Box was much better than with the traditional design. The boxplot also supports this finding (see Figure 39).

	mean time (Non-Pilot with trad. design)	***mean time (Non-Pilot with WEBER-Box)***
Mean	2.109	1.407
Variance	0.32061	0.074445556
Observations	10	10
P(T<=t) one-tail	0.001190929	
P(T<=t) two-tail	0.002381859	

Table 15. Analysis of the response time for non-pilots with the traditional design vs. the WEBER-Box

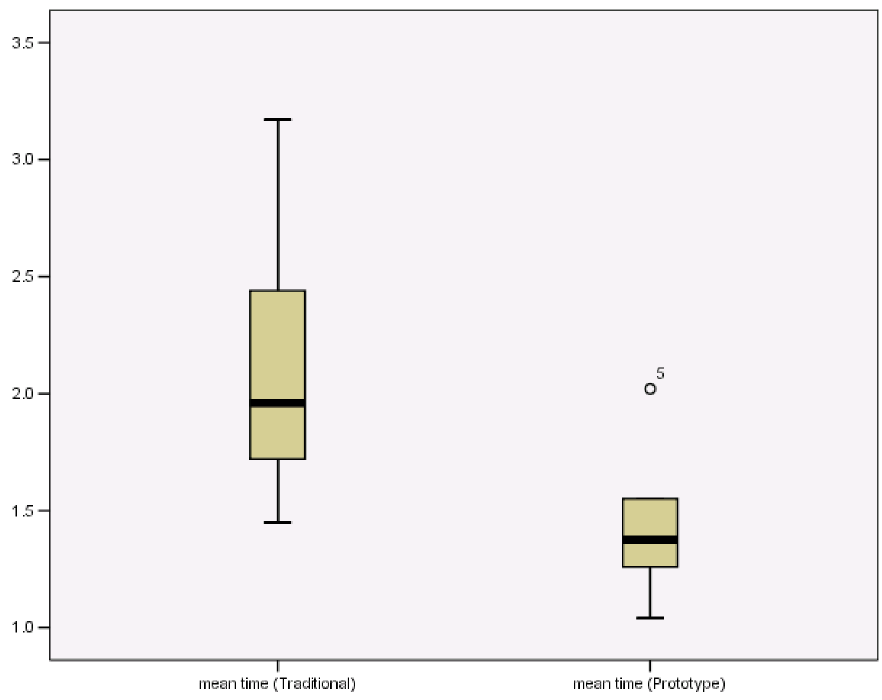


Figure 39. Graphical output of the mean response time (sec) for non-pilots with the traditional design vs. the WEBER-Box

b. *T-Test: Pilot Versus Color*

In support of the ANOVA findings a *t*-test was performed to determine whether color had an effect on response time for pilots (see Table 16). The significant result, $p < .05$, indicates that the mean response time of the pilots using the WEBER-Box was faster than with the traditional design. The boxplot also supports this finding (see Figure 40).

	mean time (Non-Pilot without color)	***mean time (Pilot with color)***
Mean	2.305	1.214
Variance	0.336538889	0.249982222
Observations	10	10
P(T<=t) one-tail	0.000137018	
P(T<=t) two-tail	0.000274036	

Table 16. Analysis of the response time for non-pilots with color vs. without color

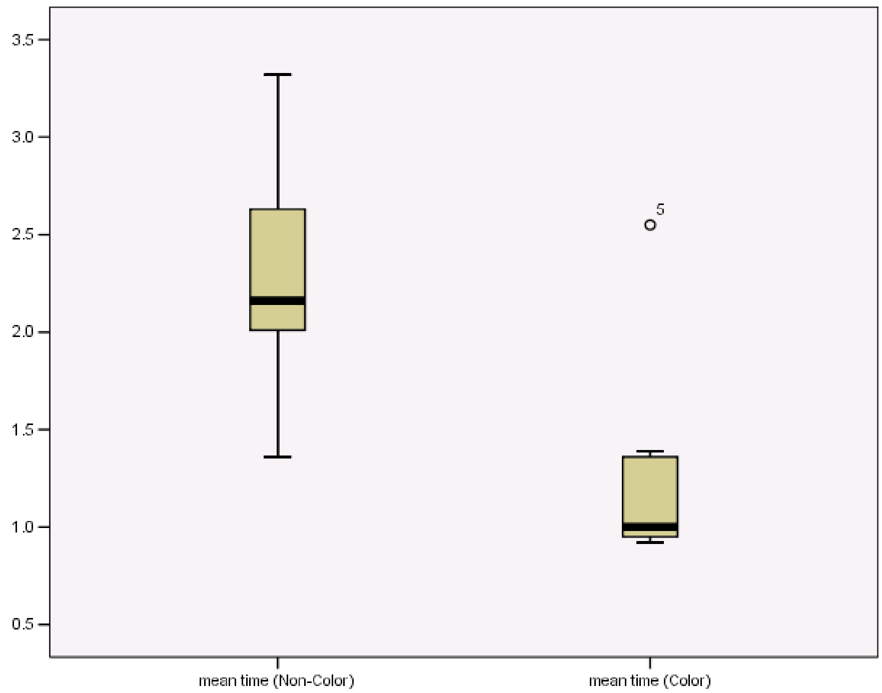


Figure 40. Graphical output of the response time (sec) of non-pilots with color vs. without color

D. POST-EXPERIMENT QUESTIONNAIRE

After the primary data collection was finished, each participant was asked to fill out the post-experiment questionnaire. This questionnaire served as an indicator of the attitude of the participants toward the two different display designs and the difference of a colored-coded support. It also provided subjective data in relation to the correct/ incorrect answers and the time each participant needed to judge the various aircraft attitudes. The raw data from the questionnaire can be seen in Table 17.

	Difficulty of Task	Difficulty judging by Traditional	Difficulty judging by Prototype	Benefits of Color-coding	Better aware with Prototype *without* Color-Coding	Better aware with Prototype *with* Color-Coding	Prototype in-/ decrease monitoring demands
ID-Participant	**1 - 5**	**1 - 5**	**1 - 5**	**1 - 5**	**1 - 5**	**1 - 5**	**1 - 5**
001	3.00	3.00	2.00	1.00	4.00	3.00	2.00
002	3.00	4.00	2.00	1.00	4.00	4.00	2.00
003	2.00	2.00	2.00	1.00	3.00	4.00	2.00
004	1.00	2.00	1.00	2.00	4.00	4.00	2.00
005	4.00	4.00	2.00	2.00	5.00	4.00	1.00
006	1.00	1.00	1.00	1.00	3.00	3.00	3.00
007	2.00	3.00	1.00	1.00	4.00	5.00	2.00
008	1.00	2.00	2.00	1.00	1.00	1.00	2.00
101	2.00	3.00	2.00	1.00	4.00	4.00	2.00
102	1.00	2.00	2.00	1.00	3.00	3.00	4.00
201	2.00	3.00	1.00	1.00	5.00	4.00	1.00
202	4.00	5.00	4.00	1.00	4.00	4.00	3.00
203	3.00	3.00	3.00	1.00	5.00	3.00	3.00
204	2.00	4.00	1.00	1.00	5.00	5.00	1.00
205	3.00	4.00	2.00	1.00	4.00	4.00	3.00
206	2.00	4.00	1.00	1.00	5.00	5.00	5.00
207	3.00	4.00	2.00	1.00	4.00	5.00	1.00
208	2.00	4.00	1.00	1.00	5.00	4.00	4.00
209	2.00	3.00	3.00	1.00	5.00	3.00	2.00
210	3.00	3.00	5.00	1.00	2.00	5.00	5.00

Table 17. Post-Experiment Questionnaire – Raw data

We calculated three different types of percentages, as shown below, to help reveal the participants' opinions:

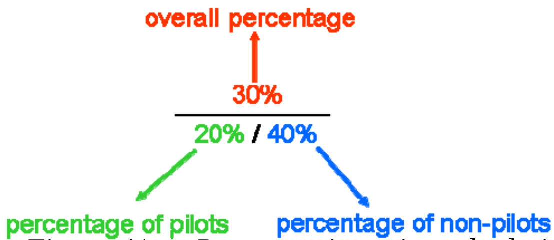


Figure 41. Post questionnaire calculation

Then we transferred these percentages again into the questionnaire (see Table 18). By doing it this way, we received a first synopsis of the summarized subjective impression of all participants.

Question	**Answer-Options**				
In general, how do you judge the difficulty of evaluating the current attitude of the aircraft?	*Very easy* **20%** **(40%/0%)**	*Somewhat easy* **40%** **(30%/50%)**	*Border line* **30%** **(20%/40%)**	*Somewhat complicated* **10%** **(5%/5%)**	*Very difficult* **0%** **(0%/0%)**
In general, how do you judge difficulty of using the traditional flight instruments for this task?	*Very easy* **5%** **(10%/0%)**	*Somewhat easy* **20%** **(40%/0%)**	*Border line* **35%** **(30%/40%)**	*Somewhat complicated* **35%** **(20%/50%)**	*Very difficult* **5%** **(0%/10%)**
In general, how do you judge the difficulty of using the WEBER-Box for this task?	*Very easy* **35%** **(30%/40%)**	*Somewhat easy* **45%** **(70%/20%)**	*Border line* **10%** **(0%/20%)**	*Somewhat complicated* **5%** **(0%/10%)**	*Very difficult* **5%** **(0%/10%)**
In general, how do you judge the benefits of color coding of an unusual attitude?	*Very good* **90%** **(80%/100%)**	*Somewhat good* **10%** **(20%/0%)**	*Border line* **0%** **(0%/0%)**	*Somewhat poor* **0%** **(0%/0%)**	*Very poor* **0%** **(0%/0%)**
Did you feel better aware of the spatial orientation of the airplane with the WEBER-Box in comparison with the traditional flight instruments, when both are without color coding of an unusual attitude?	*Much less* **5%** **(10%/0%)**	*Somewhat less* **5%** **(0%/10%)**	*Border line* **15%** **(30%/0%)**	*Somewhat more* **40%** **(50%/30%)**	*Much more* **35%** **(10%/60%)**
Did you feel better aware of the spatial orientation of the airplane with the WEBER-Box in comparison with the traditional flight instruments, when both are with color coding of an unusual attitude?	*Much less* **5%** **(10%/0%)**	*Somewhat less* **0%** **(0%/0%)**	*Border line* **25%** **(30%/20%)**	*Somewhat more* **45%** **(50%/40%)**	*Much more* **25%** **(10%/40%)**
Did having the WEBER-Box increase or decrease your monitoring demands in comparison with the traditional flight instruments?	*Greatly decreased* **20%** **(10%/30%)**	*Somewhat decreased* **40%** **(70%/10%)**	*Unaffected* **20%** **(10%/30%)**	*Somewhat increased* **10%** **(10%/10%)**	*Greatly increased* **10%** **(0%/20%)**

Table 18. Results of the post-experiment questionnaire

This subjective data provides initial evidence about the preference and acceptance of the two display designs and the opinion of the participants towards the option of a color-coded feature for detecting unusual aircraft attitudes.

The difficulty using the traditional display design for judging an attitude was rated as “border line” or “somewhat complicated” by 70% of the participants. The majority of this 70% are non-pilots, which is not surprising since pilots are trained with this instrument. Therefore, the pilots considered the use of the traditional display design relatively easy. On the other hand, 80% of all participants rated the use of the prototype display design as “easy” or “somewhat easy.” Interestingly, all of the pilots came to the same conclusion. This gives strong evidence that pilots as well as non-pilots acknowledge ease of use of the prototype design and felt that it supports their task of judging different attitudes.

The questionnaire data are quite clear regarding the use of color-coding for the judgment of unusual attitudes. All of the participants acknowledged the advantage of color-coding.

Over 70% of the participants reported that they were more aware of their spatial orientation with the prototype design (WEBER Box), independent of whether it was color-coded or not. This result was found for pilots as well as for non-pilots.

VII. CONCLUSIONS

A. OVERALL ASSESSMENT OF THE STATISTICAL RESULTS

The main question for an overall assessment was whether a significant difference between the display combinations could be determined.

In general, the effect of display design (traditional or WEBER-Box) and the effect of color coding was significant. Specifically for the probability of correct response, participants using the WEBER-Box reached a probability of correct response of 98% without color coding and 100% with color coding. The mean time also decreased when switching from the traditional display to the WEBER-Box. Adding color to the displays made this decrease even more obvious. Response times were always shorter with the WEBER-Box than with the traditional display design, and that held true for both color coded and non color coded display. Therefore the WEBER-Box was better than the traditional display for both accuracy of determining unusual attitudes and speed (response time).

The outcomes also must be considered in light of the “pilot, non-pilot” variable. Since both pilots and non-pilots participated, one has to take into consideration that pilots would be expected to perform better. They are not only familiar with the traditional display design, but they are also trained specifically on this kind of task, judging an attitude and then starting a recovery operation when necessary. This also enhances their skills to read and interpret flight instruments. Due to time constraints on the other hand, there was very little time to familiarize the non-pilots with the different display designs and train them for the task of judging an aircraft attitude.

The answers in the post-experiment questionnaire confirmed the outcome of the statistical analysis. As mentioned in the previous chapter, there is agreement between the subjective response of the participants in the post-experiment questionnaire and the objective data. For example, both pilots and non-pilots felt that adding color to each of the displays increased their ability for spatial awareness and spatial orientation. 80% of the pilots and 100% of the non-pilots judged the color-coding to be beneficial. Comparing the traditional display design with the prototype display design, more than

70% of the participants preferred the new design, independent of adding color or not, compared to the old design. This result gains importance because 60% of the pilots judged an improved awareness with the prototype design as “somewhat more” or “much more”.

A detailed look into the data shows that not only the probability of correct answers increased, but even more important, the time required to judge the current attitude decreased significantly. For example the mean response times changed as follows:

- traditional to prototype: from 1.92 sec to 1.37 sec (29% reduction)
- without color to color: from 1.99 sec to 1.30 sec (36% reduction)
- traditional without color to traditional with color: from 2.35 sec to 1.49 sec (37% reduction)
- prototype without color to prototype with color: from 1.62 sec to 1.09 sec (33% reduction)

By the results of the ANOVA and the additional *t*-tests, one can see that the prototype design enabled the participants to judge the situation faster and more accurately. These results clearly show the superiority of the prototype display design (WEBER Box).

B. DISCUSSION AND CONCLUSION

To understand the findings of this study, one must consider the purpose of the new prototype design. It was built to support pilots or operators of UAVs in extreme situations. With the findings of the research questionnaire, we were able to identify a current issue of the UAV community, in our case of the Predator UAV. That is, the WEBER-Box would help in the recognition of the current aircraft attitude, facilitate recovery when an unusual attitude existed, and help to prevent misperception of an unusual attitude. Based on this information, we developed the experiment and compared the traditional display design with the new design (WEBER Box). We also evaluated the color factor and its two levels, with or without color-coding.

In the experimental task, the participants judged their spatial attitude in a static environment. Based on the level of significance of α = 0.05, the outcome was remarkably obvious. Using the WEBER Box, performance increased in both accuracy and response time. For the dependent variable “correct response,” using the prototype display design improved performance by 105%. When using the color-coded feature, the same 105% gain of performance was found. The results are even more significant for the dependent variable “mean time to respond” where the performance improved by 145% using the new prototype design.

The value of the prototype display also was supported by the post-experiment questionnaire and by comments and suggestions as the final feedback after completing the experiment. Most of the participants stated that the new display design was very helpful in judging the aircraft attitude task. They felt an improvement in their spatial awareness and the new design helped them to decrease the time for correctly judging their attitude. Thus, the prototype display design made it easier to accomplish their task. By adding color to the displays, it was even easier to judge the current attitude and the percentage of correct responses increased to almost 100% or even reached a level of 100% in the case of the new design. Likewise, the time to achieve a correct response decreased significantly too.

Therefore the combination of the new prototype design together with color-coding showed a clear increase of performance compared to the traditional display design without color that is currently being used.

C. FUTURE RESEARCH

As is often the case in research, in addition to answering some questions, other questions and suggestions have been raised. Most of them fall in the category of suggested design improvements, in our case design improvements of the new prototype design in combination with the color support. These can be summarized as follows:

- What is the ideal size of the new prototype design? Since it provides a numerical output of pitch and roll, the question is how small could it be to still fit in the environment of a ground control station of UAV but with a font size still large enough to read the numbers.

- Is it possible to decrease the time for judging the attitude by placing the digital readout of pitch and roll to a more central location in the display? Currently there is still an eye movement necessary from the animated aircraft to the digital pitch and roll values, since it is not possible to see all of the information with one view.
- Would it be better to change the color of the entire aircraft avatar instead of the output of pitch and roll digital display, when reaching an unusual attitude?
- Can the output pitch and roll be represented in a different way so that the aircraft avatar and the output can be seen at the same time? A possible solution to this question is, giving the new prototype display design a background like a grid. The aircraft avatar would “fly” on top of the grid and pitch and roll as additional numerical output could be displayed sideways to this grid.

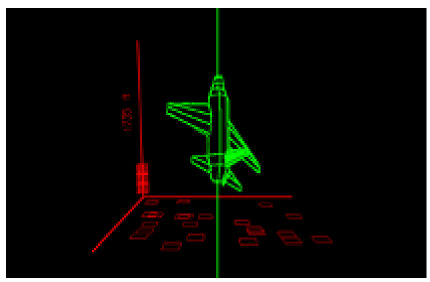
APPENDIX A. RESEARCH QUESTIONNAIRE

Naval Postgraduate School, LTC Thomas Zirkelbach, German Army   Jan 2007

Background Information

Spatial awareness and the skills of an operator to transition from the current spatial attitude into the necessary spatial orientation and position mainly depend on human performance in spatial orientation tasks. Degraded spatial awareness, particularly in extreme flight situations, may lead to loss of equipment and to lower operational effectiveness. How to maintain and improve spatial awareness is one of the major issues in complex 3D environments. In particular, orientation tasks in 3D environments with many degrees of freedom are very difficult to accomplish.

Based on these findings Maj Axel Weber (GE) has developed in his thesis "Application of Avatars in Display Design to support Spatial Awareness in Extreme Flight Situations" a prototype display design that helps to recognize and recover from an unusual attitude faster and more accurate compared to a traditional display design.



Screenshot of the new prototype display design, called WEBER-Box

I am expanding this work researching with my thesis "Pictorial Display Design to enhance Spatial Awareness of Operators in Unmanned Aviation" possible applications of the WEBER-Box for UAVs.

Therefore I am currently looking for UAV incidents which will be the initial position for an experiment that should have a realistic background. Therefore I am assuming that operations of large UAVs are normally not flown in unusual attitude, but nevertheless occasionally it occurs. One basic question is "How often do the operators get unintended into an unusual attitude?" Thus I have elicited and focused through my research on two general approaches.

<u>Approach 1: Recovery from an unusual attitude</u>
Currently available literature states that incidents occur if the data link is interrupted, will be reestablished and a recovery of the UAV is still not possible. I am also thinking of a different situation where there are no problems with the data-link or the GPS-Signal but the internal computer which is responsible for the stabilization system fails and the UAV e. g. Predator has to be recovered manually by the operator in the Ground Control Station. In such a case I assume the UAV will be in an unusual attitude before the recovery even starts.

Approach 2: Launch and Recovery

With this approach I focus on the topic how the WEBER-Box could support recovery operations.

Naval Postgraduate School, LTC Thomas Zirkelbach, German Army Jan 2007

Questionnaire

1) We have a prototype display design that helps to recognize and recover from an unusual attitude.
   a) Can you think of a situation where it can be used?

2) a) Have you experienced situations of unusual attitude?
   b) Which UAV has been involved?
   c) What was the cause for this unusual attitude?
   d) How did you recover it, autonomously or manually?
   e) If manually, which instruments did you use?
   f) Have you been successful?

3) a) Have you experienced situations of unusual attitude when handing over a UAV from one Ground Station to another?
   b) If yes, which UAV has been involved?
   c) Please describe:

4) a) Have you experienced situations of unusual attitude after an interrupted data link was restored?
   b) If yes, which UAV has been involved?
   c) Please describe:

5) Assume the following scenario: a Predator has no data-link interruption and the GPS signal works, but its internal computer responsible for its autonomous flying fails.
   a) Have you ever experienced a situation like this?
   b) Does the operator take over in remote control?
   c) Did this situation cause an unusual attitude?

6) Can you launch and recover in instrument conditions?

7) If you had to accomplish evasive maneuvers to escape anti-aircraft fire,
   a) Would you do this in remote control?
   b) Which flight instruments would you be using?
   c) How difficult would this be?

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APPENDIX B. IRB APPLICATION

Michael E. McCauley, Ph.D.
Operations Research Department
Glasgow Hall
Naval Postgraduate School
Monterey, California 93943

831-656-2191
DSN: 756-2191
Fax: 831-656-2595
memccaul@nps.edu

To: Protection of Human Subjects Committee

Subject: Application for Human Subjects Review for
Pictorial Display Design to enhance Spatial Awareness of Operators in Unmanned Aviation

1. Attached is a set of documents outlining a proposed experiment to be conducted over the three month to support the thesis of LTC Thomas Zirkelbach, GE.

2. We are requesting approval of the described experimental protocol. An experimental outline is included for your reference that describes the methods and measures we plan to use.

3. We include the consent forms, privacy act statements, all materials and forms that a subject will read or fill-out, and the debriefing forms (if applicable) we will be using in the experiment.

4. We understand that any modifications to the protocol or instruments/measures will require submission of updated IRB paperwork and possible re-review. Similarly, we understand that any untoward event or injury that involves a research participant will be reported immediately to the IRB Chair and NPS Dean of Research.

Michael E. McCauley

<table>
<tr><td>APPLICATION FOR
HUMAN SUBJECTS REVIEW (HSR)</td><td>NPS IRB NUMBER (to be assigned by RSPO)</td></tr>
<tr><td colspan="2">PRINCIPAL INVESTIGATOR(S) (Full Name, Code, Telephone)
Michael E. McCauley, Ph.D., Monterey, CA 93943, Phone: 831 656-2191
(Thesis of LTC Thomas Zirkelbach, GE)</td></tr>
<tr><td colspan="2">TITLE OF EXPERIMENT
Does an outside-in aircraft animation display help UAV operators to accurately perceive unusual attitudes?</td></tr>
<tr><td colspan="2">APPROVAL REQUESTED [X] New [ ] Renewal [ ] Amendment</td></tr>
<tr><td colspan="2">LEVEL OF RISK [ ] Exempt [X] Minimal [ ] More than Minimal
Justification: Since there is no wide field of view (FOV) terrain display, simulator sickness is extremely unlikely. A prior study using this prototype display found zero incidence of simulator sickness.</td></tr>
<tr><td>WORK WILL BE DONE IN (Site/Bldg/Rm)
NPS, Watkins Hall, RM 212B</td><td>ESTIMATED NUMBER OF DAYS TO COMPLETE
30</td></tr>
<tr><td>MAXIMUM NUMBER OF SUBJECTS
50</td><td>ESTIMATED LENGTH OF EACH SUBJECT'S PARTICIPATION
2 hours (1 hour in flight simulation)</td></tr>
<tr><td colspan="2">SPECIAL POPULATIONS THAT WILL BE USED AS SUBJECTS

[ ] Subordinates [ ] Minors [X] NPS Students [ ] Special Needs (e.g. Pregnant women)

Specify safeguards to avoid undue influence and protect subject's rights:
Participant Consent Form & Minimal Risk Statement</td></tr>
<tr><td colspan="2">SCIENTIFIC MERIT REVIEW (Check all that apply)

[ ] This research is part of a funded project (Job Order Number)

[X] This research is a student thesis (Attach a copy of the approved thesis proposal)

[ ] Other (Attach a complete research proposal)</td></tr>
<tr><td colspan="2">OUTSIDE COOPERATING INVESTIGATORS AND AGENCIES
None
[ ] A copy of the cooperating institution's HSR decision is attached.</td></tr>
</table>

DESCRIPTION OF RESEARCH (attach additional sheet if needed). **Methodology attached**
I have read and understand NPS Notice on the Protection of Human Subjects. If there are any changes in any of the above information or any changes to the attached Protocol, Consent Form, or Debriefing Statement, I will suspend the experiment until I obtain new IRB approval. SIGNATURE______________________________________ DATE________________

Methodology

Experiment Goals and Purpose
This research will investigate the effectiveness of a prototype display for pilot/operator recognition of aircraft/UAV attitude.

Research Questions
- Will the new display design help operators to recognize aircraft attitude accurately?
- Will the new design help in discriminating between a normal and unusual attitude?
- Will the new design help prevent misperception of an unusual attitude?
- Will the new design reduce errors in recovery from unusual attitudes?
- Will the new design support the substitution of operators for trained pilots in unmanned aviation tasks?
- What will be the level of user acceptance of operators and pilots regarding the new design?

Participants
The participants will be randomly assigned on a volunteer basis from students and faculty of NPS. The study will involve at the most 50 participants. It is intended to split them equally into 25 pilots and 25 non-pilots.

Apparatus
The experiment will take place at the Naval Postgraduate School, Monterey, California, Watkins Building, room 212B. Two workstations will be used. Workstation 1 is for instruction and training while Workstation 2 will be established for the underlying experiment.

Workstation 1:
The computer-generated images will be displayed on a 19” computer monitor with a 1024 x 768 pixel resolution. The pictures of the flight situations were generated by screenshots of the commercial flight simulator software X-Plane™, version 7.13 and by screenshots of the WEBER-Box program. The pictures were stored in a PowerPoint™ slideshow to ensure that every participant will see the different aircraft attitudes in the same order. This slideshow will be used to explain the differences between a usual and unusual attitude. The simulation of the flight situations also will be generated by X-Plane™ and by the WEBER-Box program. The predefined simulations of usual and unusual attitude will be stored in X-Plane™ to help the participants to gain a better understanding of this complex situation in a dynamic environment.

Workstation 2:
The computer-generated images will be displayed on two 19” computer monitors with a 1024 x 768 pixel resolution. The two screens will be located on top of each other, similar to the ground station of a Predator UAV. The simulation of the flight situations will be generated by the commercial flight simulator software X-Plane™, version 7.13 and by the

WEBER-Box program. The predefined simulations of usual and unusual attitude will be stored in X-Plane™ to ensure that every participant will see the different attitudes in the same order.

Procedures

The overall experiment will be subdivided into four phases.

Phase one – Preparation:

The participant will be asked to fill out the necessary paperwork, including a consent form, a privacy act statement, a minimal-risk information form, and an initial/ demographic questionnaire.

Phase two – Introduction and Training

The participant will be introduced to the experiment, receiving information about the UAV, the task as an operator of the UAV, and details about usual and unusual attitudes. The participant also will watch a 10-minute introduction video of usual and unusual attitudes as displayed by the traditional flight instruments and by the WEBER-Box. This pre-experimental period, phase one and two, will take approximately 25 minutes.

Phase three – Experiment

The participant will start with the first experimental sub-task. Each of his or her 14 trials will be scheduled for 120 seconds. The first two trials will be practice trials. The experimenter will start the prepared simulation of several flight situations that end in a usual or unusual attitude and, after 120 seconds, the simulation will stop with a picture of flight instruments in a certain flight situation. The participant will judge the “frozen” situation as a usual or unusual attitude. Then, the experimenter will initiate the next trial until the participant has finished twelve trials, plus two test trials.

After accomplishing the first block of experiments, the participant will take a 5-minute break. Then the participant will start the second experimental task. All the participants will be exposed to all of the instrument setups and all of the sub-experiments (a within-subjects design). Each participant will be presented with seven trails of usual attitude with traditional design and seven trails of unusual attitude with the traditional design. Then the same procedure will apply with the new display design, the WEBER Box.

Phase four – Questionnaire

When finished, the participant will be asked to fill out the post-experimental questionnaire. This completes the experimental session.

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APPENDIX C. IRB APPROVAL

Naval Postgraduate School
Institutional Review Board (IRB)

22-Feb-07

From: LT Brent Olde, Ph.D.
To: Research Professor Michael McCauley

Subject: YOUR PROJECT: PICTORIAL DISPLAY DESIGN TO ENHANCE SPATIAL AWARENESS OF OPERATORS IN UNMANNED AVIATION

1. The NPS IRB is pleased to inform you that the NPS Institutional Review Board has approved your project (NPS IRB# NPS20070042).

2. The NPS IRB was originally certified by BUMED on 26 July 2002 and has been re-certified until 30 March 2007.

3. This approval is valid for one year from this date. Please submit a copy of all records and consent forms to the Research and Sponsored Programs Office (Laura Ann Small, Halligan Hall, Room 201B) at the conclusion of this project.

4. If your protocol changes at any time, you will need to resubmit your project proposal to the NPS IRB.

Sincerely,

Lt Brent Olde, Ph.D.
Chair
NPS Institutional Review Board

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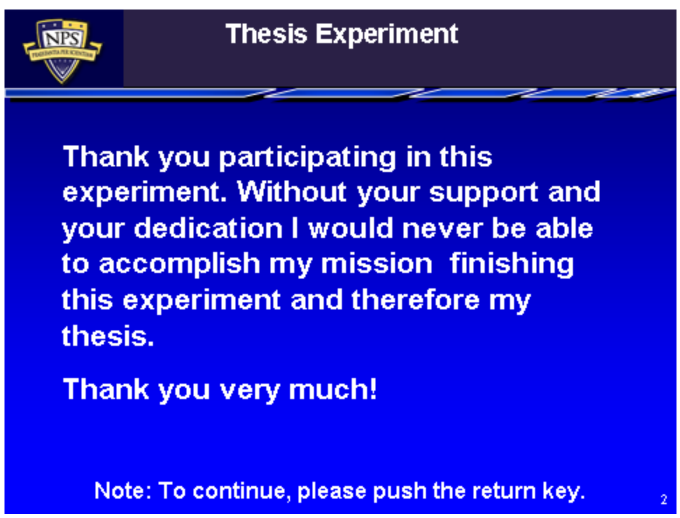
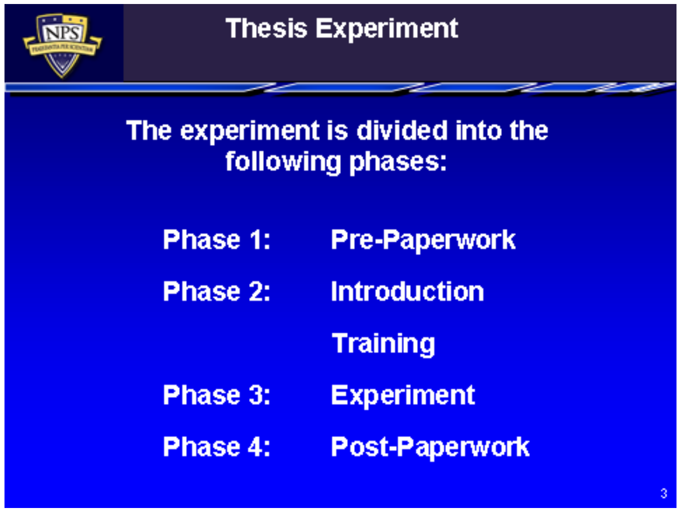
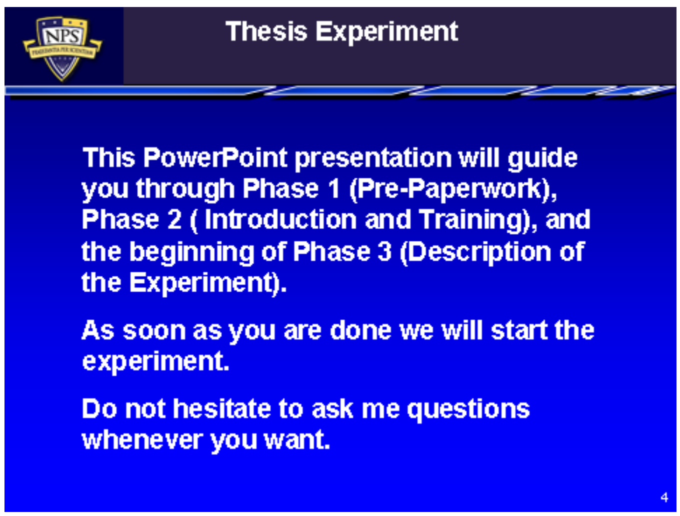
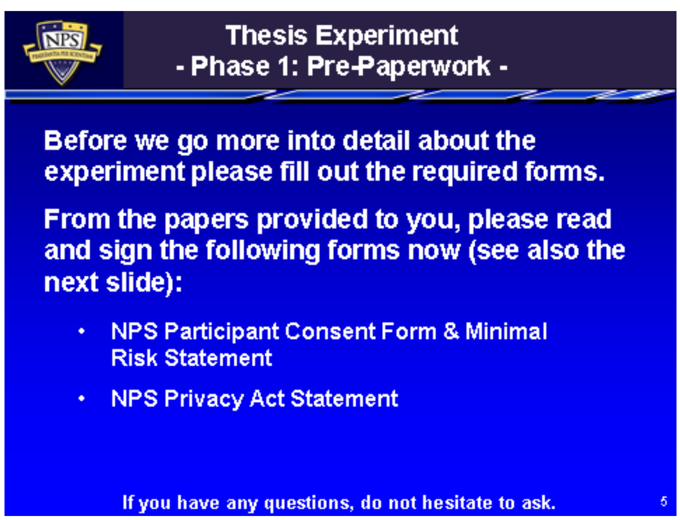
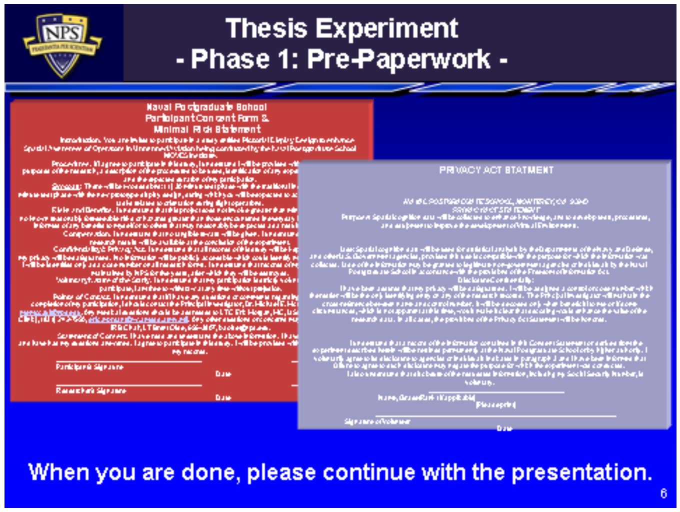
APPENDIX D. INTRODUCTION / TASK DESCRIPTION

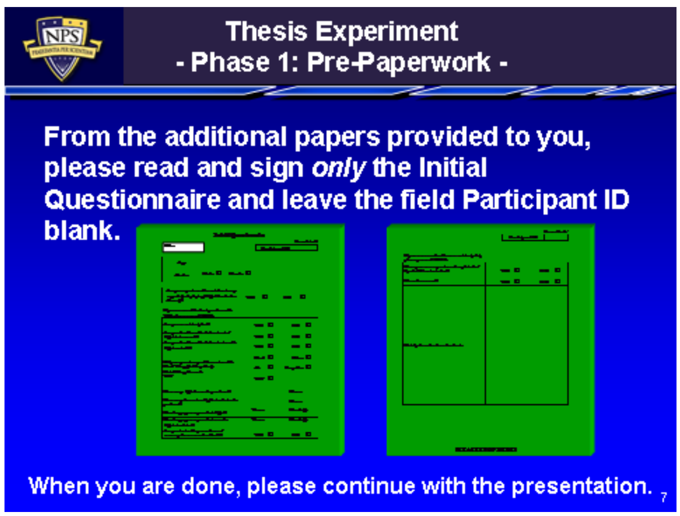


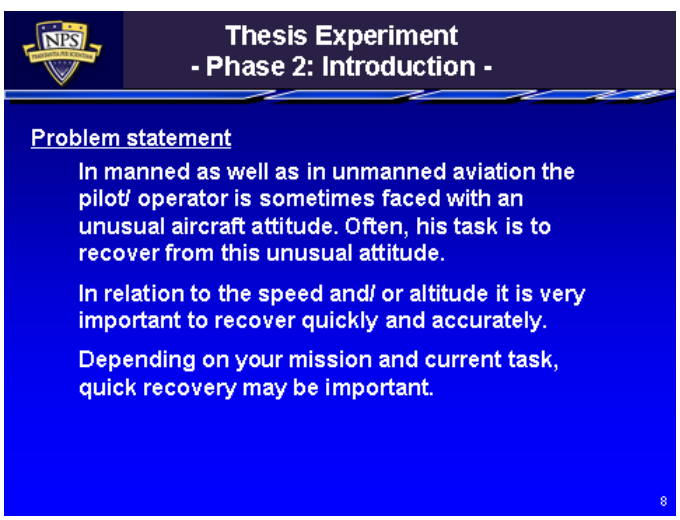

Thesis Experiment
The experiment is divided into the following phases:
Phase 1: Pre-Paperwork
Phase 2: Introduction
Training
Phase 3: Experiment
Phase 4: Post-Paperwork
3


Thesis Experiment
This PowerPoint presentation will guide you through Phase 1 (Pre-Paperwork), Phase 2 (Introduction and Training), and the beginning of Phase 3 (Description of the Experiment).
As soon as you are done we will start the experiment.
Do not hesitate to ask me questions whenever you want.
4


Thesis Experiment
- Phase 1: Pre-Paperwork -
Before we go more into detail about the experiment please fill out the required forms.
From the papers provided to you, please read and sign the following forms now (see also the next slide):
• NPS Participant Consent Form & Minimal Risk Statement
• NPS Privacy Act Statement
If you have any questions, do not hesitate to ask.
5


Thesis Experiment
- Phase 1: Pre-Paperwork -
Naval Postgraduate School
Participant Consent Form &
Minimal Risk Statement
PRIVACY ACT STATEMENT
When you are done, please continue with the presentation.
6


Thesis Experiment
- Phase 1: Pre-Paperwork -
From the additional papers provided to you, please read and sign *only* the Initial Questionnaire and leave the field Participant ID blank.
When you are done, please continue with the presentation.
7


Thesis Experiment
- Phase 2: Introduction -
Problem statement
In manned as well as in unmanned aviation the pilot/ operator is sometimes faced with an unusual aircraft attitude. Often, his task is to recover from this unusual attitude.
In relation to the speed and/ or altitude it is very important to recover quickly and accurately.
Depending on your mission and current task, quick recovery may be important.
8

Thesis Experiment
- Phase 2: Introduction -

What is *unusual attitude*?

… “an unusual attitude is defined in the industry as one where pitch unintentionally exceeds 25 degrees nose up or 10 degrees nose down, bank angle unintentionally exceeds 45 degrees, and the airspeed is inappropriate for the conditions.”

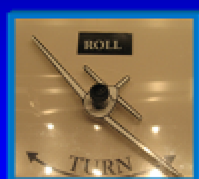
For this experiment we will focus on pitch and bank angle. We will not monitor the airspeed, since this is not the main interest.

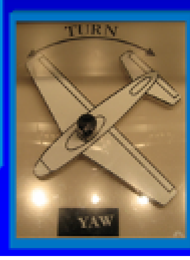
9

Thesis Experiment
- Phase 2: Introduction -

General aviation information

The basic flight maneuvers are displayed below. For this experiment Roll (Bank) Angle and Pitch are the important ones.





10

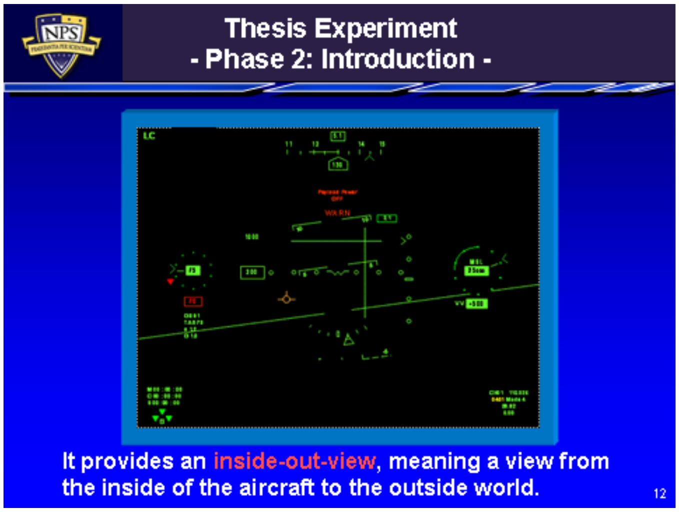
Thesis Experiment
- Phase 2: Introduction -

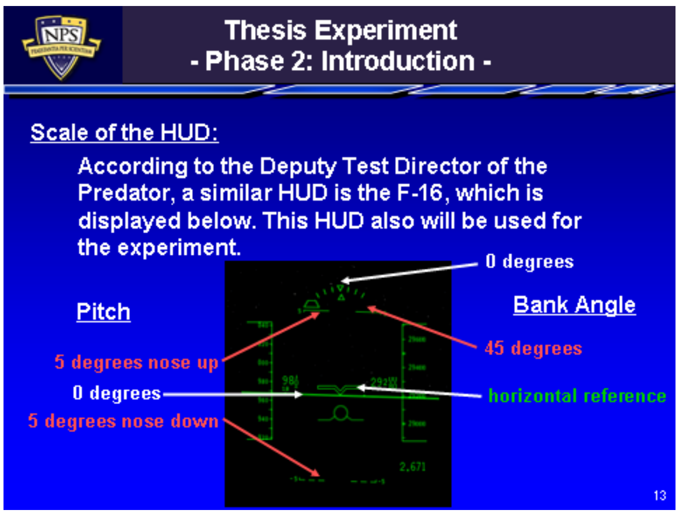
Instruments - Attitude Indicator

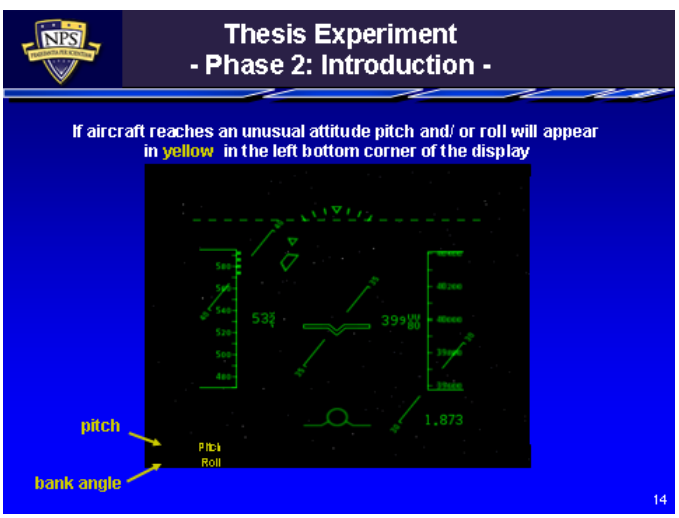
Since the beginning, pilots have depended heavily on their instruments. One of the most important, and also one of the oldest instruments, is the *attitude indicator* which provides information to the pilot about his current situation in space.

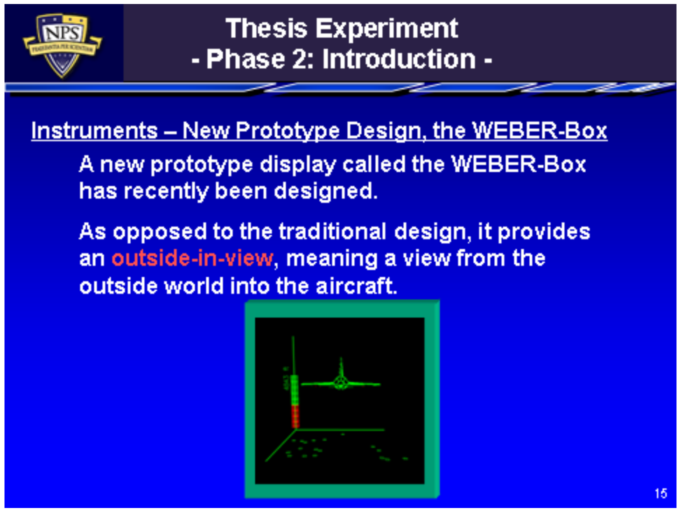
The Unmanned Aerial Vehicle (UAV) Predator, which is of interest in this experiment, displays the information of pitch and angle of bank in a Heads-Up-Display (HUD) that you can see on the following slide.

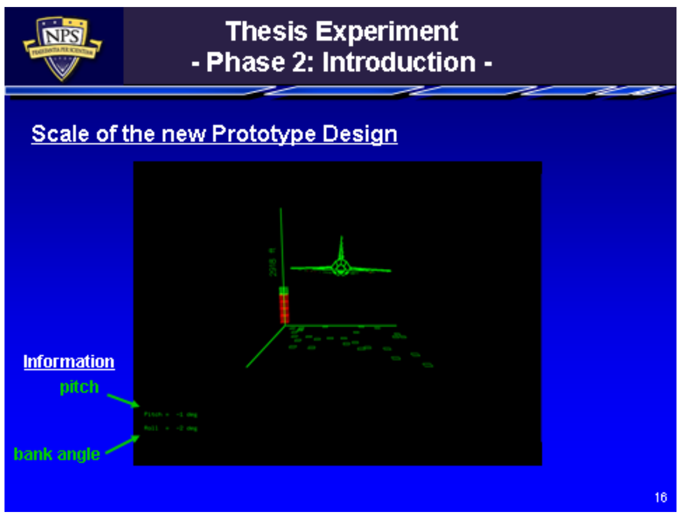
11

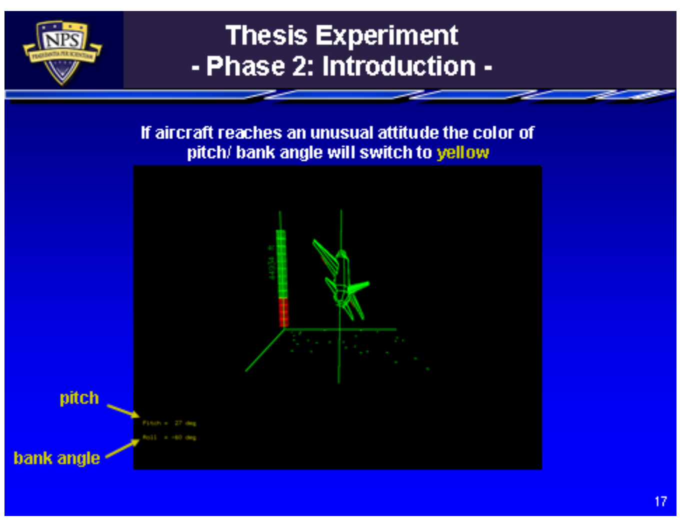

Thesis Experiment
- Phase 2: Introduction -
It provides an inside-out-view, meaning a view from
the inside of the aircraft to the outside world.
12

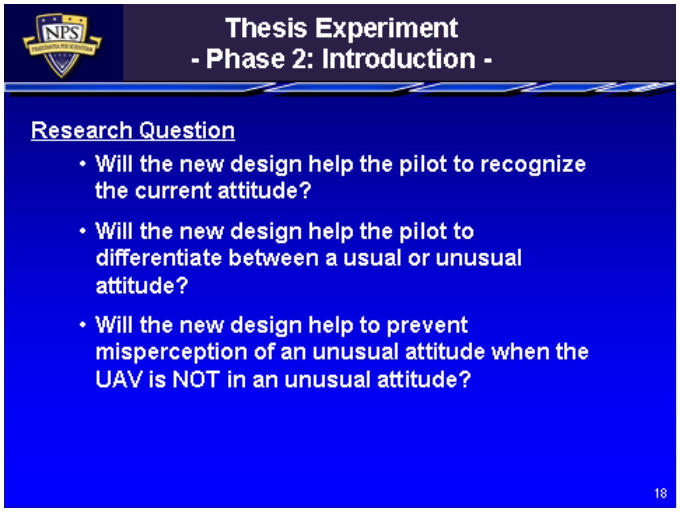

Thesis Experiment
- Phase 2: Introduction -
Scale of the HUD:
According to the Deputy Test Director of the
Predator, a similar HUD is the F-16, which is
displayed below. This HUD also will be used for
the experiment.
0 degrees
Pitch
Bank Angle
5 degrees nose up
45 degrees
0 degrees
horizontal reference
5 degrees nose down
2,671
13

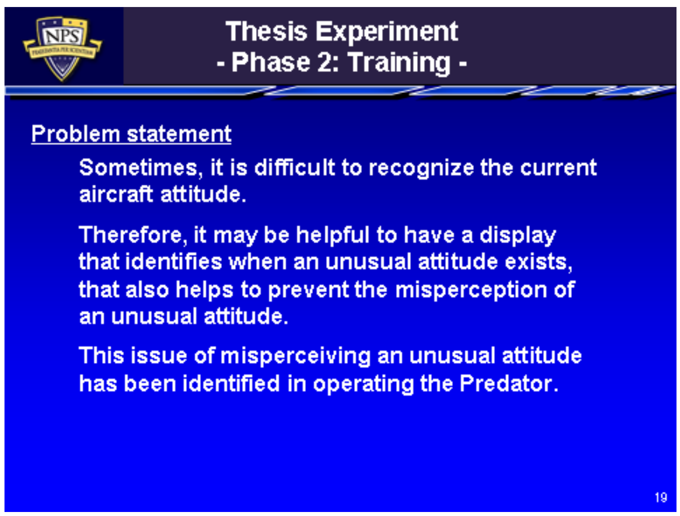

Thesis Experiment
- Phase 2: Introduction -
If aircraft reaches an unusual attitude pitch and/ or roll will appear
in yellow in the left bottom corner of the display
1.873
pitch
Pitch
Roll
bank angle
14

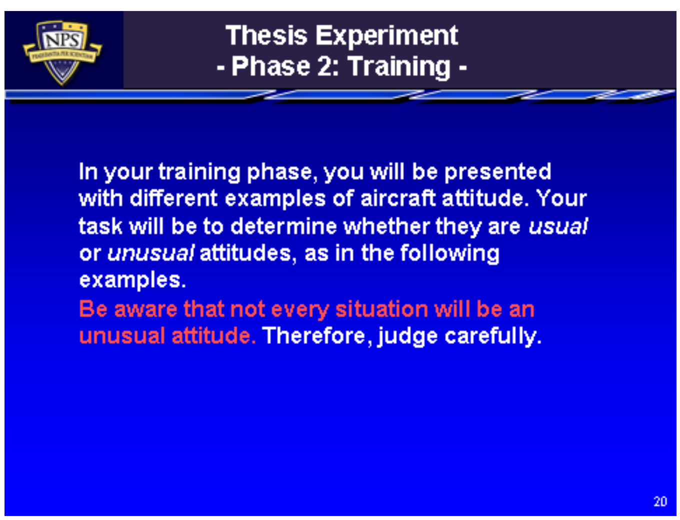

Thesis Experiment
- Phase 2: Introduction -
Instruments – New Prototype Design, the WEBER-Box
A new prototype display called the WEBER-Box has recently been designed.
As opposed to the traditional design, it provides an outside-in-view, meaning a view from the outside world into the aircraft.
15

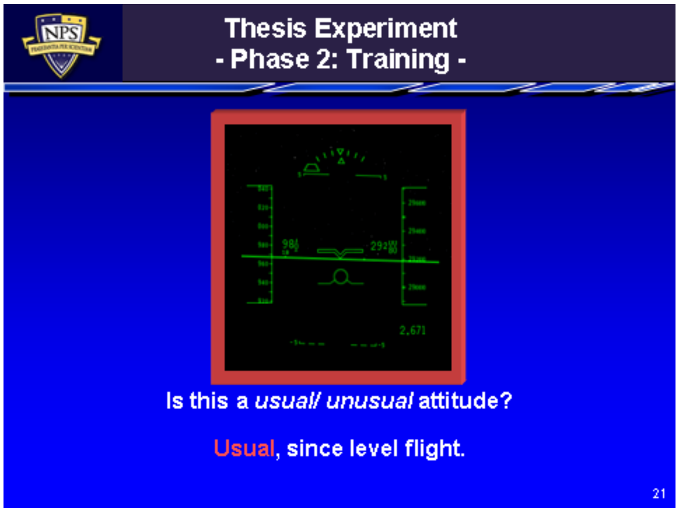

Thesis Experiment
- Phase 2: Introduction -
Scale of the new Prototype Design
Information
pitch
bank angle
16

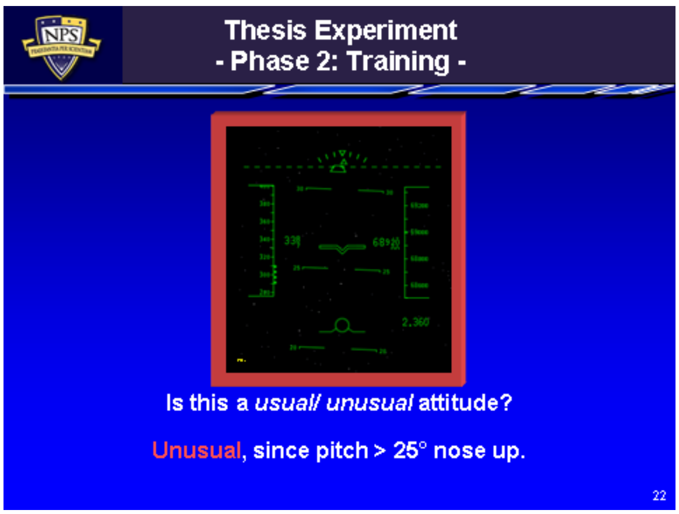

Thesis Experiment
- Phase 2: Introduction -
If aircraft reaches an unusual attitude the color of pitch/ bank angle will switch to yellow
pitch
bank angle
17

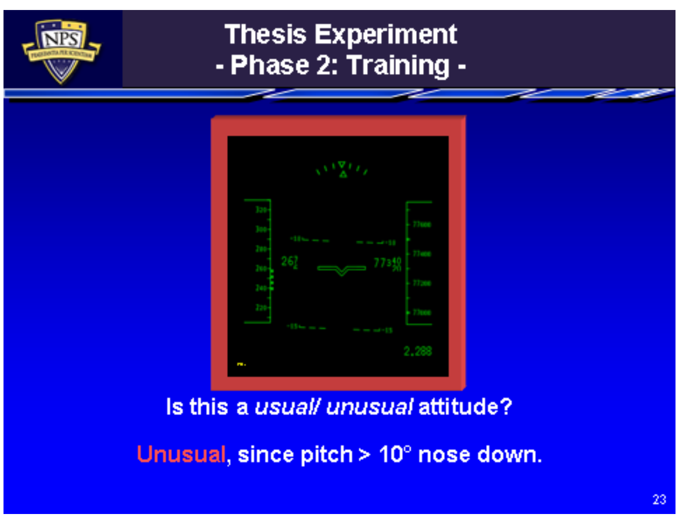

Thesis Experiment
- Phase 2: Introduction -
Research Question
• Will the new design help the pilot to recognize the current attitude?
• Will the new design help the pilot to differentiate between a usual or unusual attitude?
• Will the new design help to prevent misperception of an unusual attitude when the UAV is NOT in an unusual attitude?
18

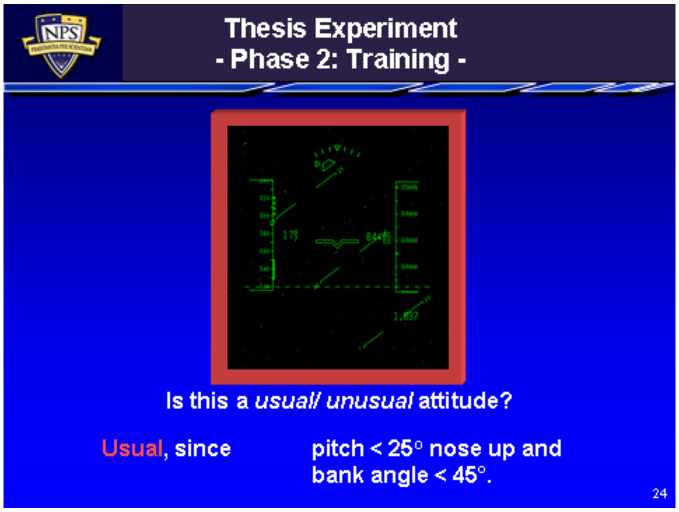

Thesis Experiment
- Phase 2: Training -
Problem statement
Sometimes, it is difficult to recognize the current aircraft attitude.
Therefore, it may be helpful to have a display that identifies when an unusual attitude exists, that also helps to prevent the misperception of an unusual attitude.
This issue of misperceiving an unusual attitude has been identified in operating the Predator.
19

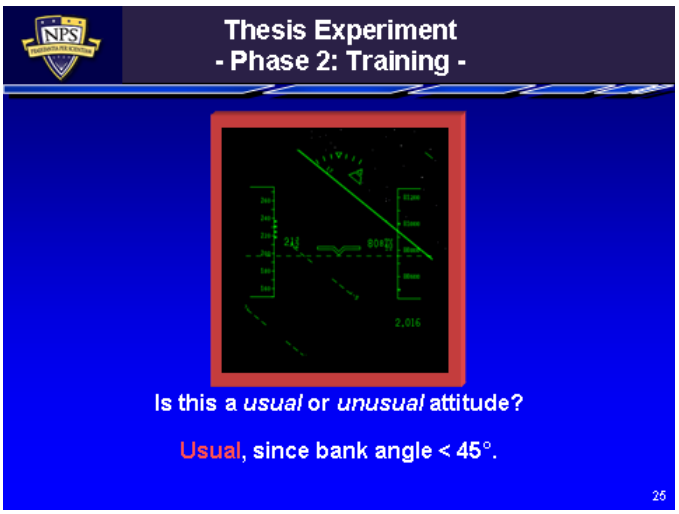

Thesis Experiment
- Phase 2: Training -
In your training phase, you will be presented with different examples of aircraft attitude. Your task will be to determine whether they are *usual* or *unusual* attitudes, as in the following examples.
Be aware that not every situation will be an unusual attitude. Therefore, judge carefully.
20

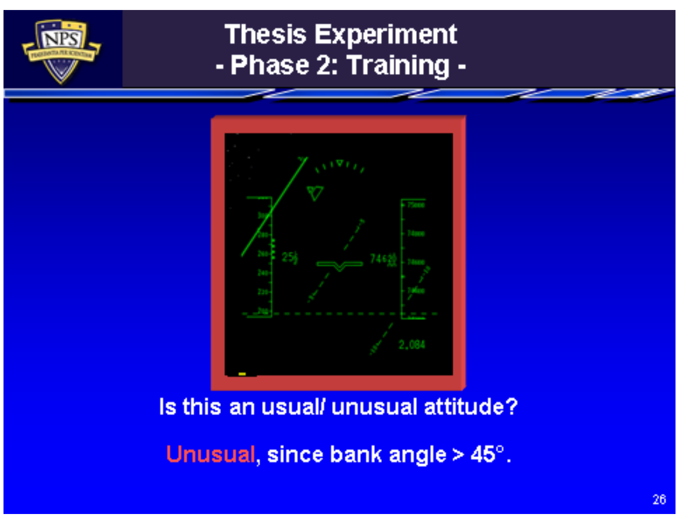

Thesis Experiment
- Phase 2: Training -
Is this a *usual/ unusual* attitude?
Usual, since level flight.
21

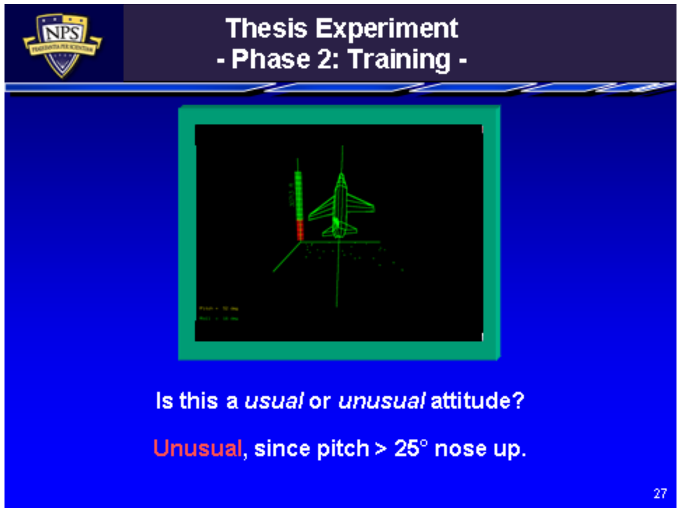

Thesis Experiment
- Phase 2: Training -
Is this a *usual/ unusual* attitude?
Unusual, since pitch > 25° nose up.
22

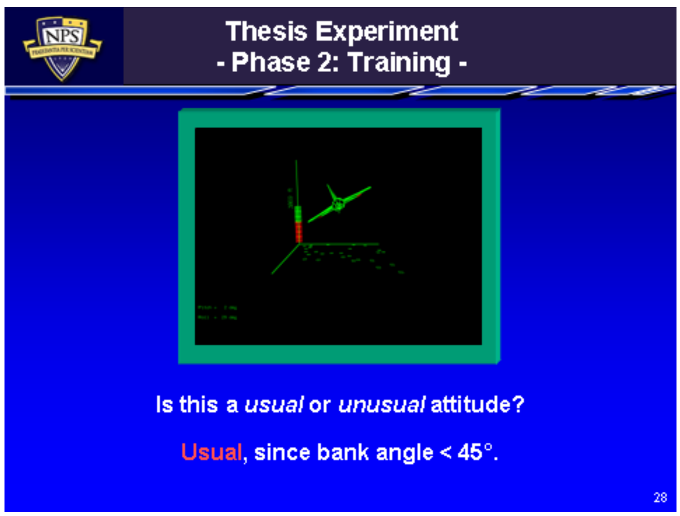

Thesis Experiment
- Phase 2: Training -
Is this a *usual/ unusual* attitude?
Unusual, since pitch > 10° nose down.
23

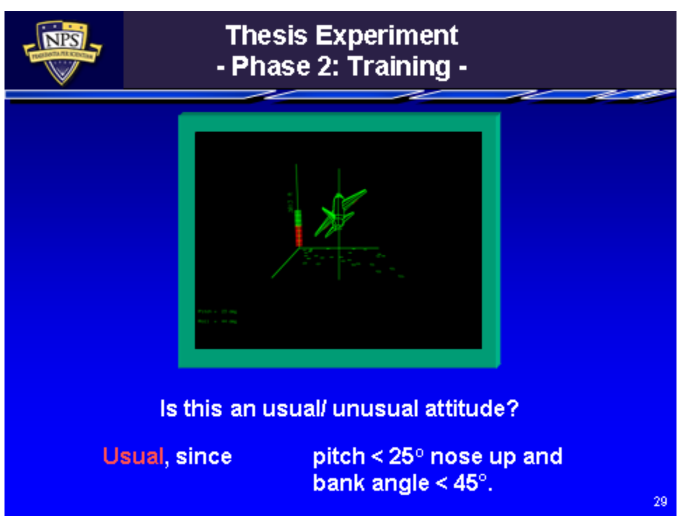

Thesis Experiment
- Phase 2: Training -
Is this a usual/ unusual attitude?
Usual, since pitch < 25° nose up and bank angle < 45°.
24

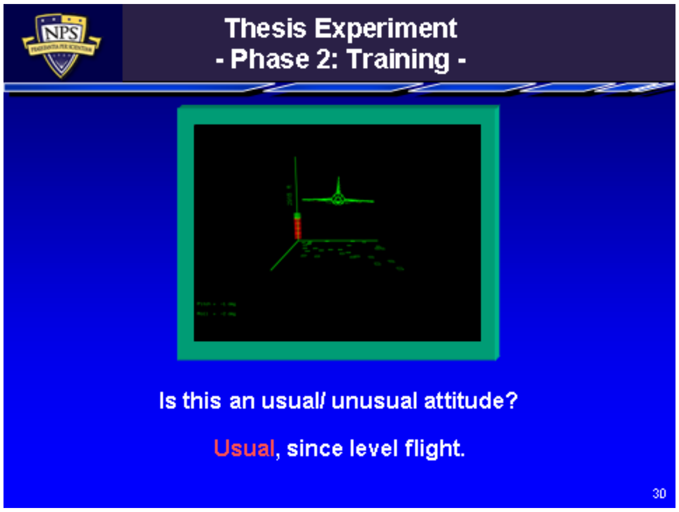

Thesis Experiment
- Phase 2: Training -
Is this a usual or unusual attitude?
Usual, since bank angle < 45°.
25

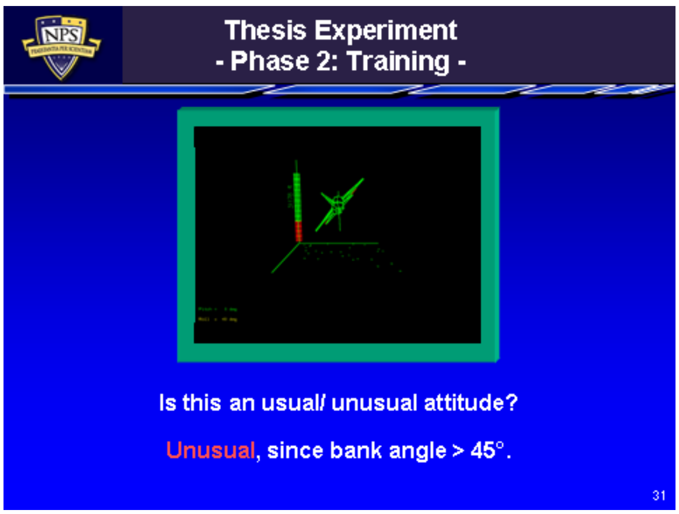

Thesis Experiment
- Phase 2: Training -
Is this an usual/ unusual attitude?
Unusual, since bank angle > 45°.
26

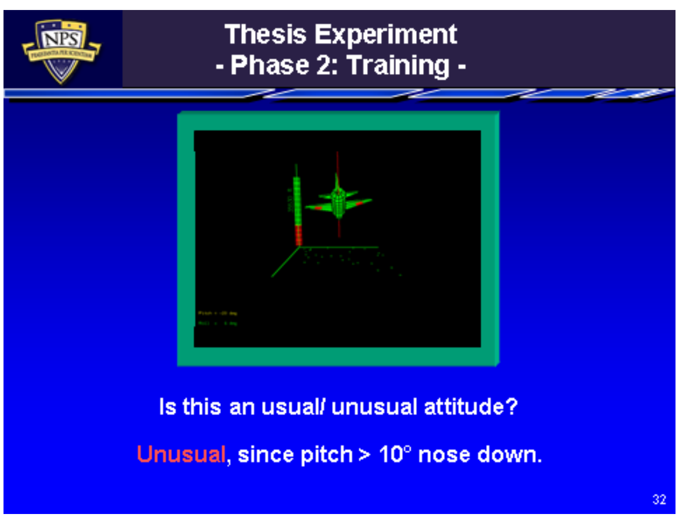

Thesis Experiment
- Phase 2: Training -
Is this a *usual* or *unusual* attitude?
Unusual, since pitch > 25° nose up.
27


Thesis Experiment
- Phase 2: Training -
Is this a *usual* or *unusual* attitude?
Usual, since bank angle < 45°.
28


Thesis Experiment
- Phase 2: Training -
Is this an usual/ unusual attitude?
Usual, since pitch < 25° nose up and
bank angle < 45°.
29


Thesis Experiment
- Phase 2: Training -
Is this an usual/ unusual attitude?
Usual, since level flight.
30


Thesis Experiment
- Phase 2: Training -
Is this an usual/ unusual attitude?
Unusual, since bank angle > 45°.
31


Thesis Experiment
- Phase 2: Training -
Is this an usual/ unusual attitude?
Unusual, since pitch > 10° nose down.
32

Thesis Experiment
- Phase 3: Experiment -

The Task

You are currently assigned as a pilot of the UAV MQ-1 Predator.

33

Thesis Experiment
- Phase 3: Experiment -

Features of the Predator "For your information"

Primary Function:	Armed reconnaissance, airborne surveillance, target acquisition
Contractor:	General Atomics Aeronautical Systems Incorporated
Power Plant:	Rotax 914 four cylinder engine with 101 horsepower
Length:	27 feet (8.22 meters)
Height:	6.9 feet (2.1 meters)
Weight:	1,130 pounds (512 kg) empty, maximum takeoff weight 2,250 pounds (1,020 kg)
Wingspan:	48.7 feet (14.8 meters)
Speed:	Cruise speed around 84 mph (70 knots), up to 135 mph
Range:	up to 400 nautical miles (454 miles)
Ceiling:	up to 25,000 feet (7,620 meters)
Fuel Capacity:	665 pounds (100 gallons)
Payload:	450 pounds (204 kg)
Armament:	two laser-guided AGM-114 Hellfire anti-tank missiles

34

Thesis Experiment
- Phase 3: Experiment -

General information

The MQ-1 Predator is a medium-altitude, long-endurance, remotely piloted aircraft. It's primary mission is interdiction and conducting armed reconnaissance against critical, perishable targets. When it is not actively pursuing its primary mission, it acts as the Joint Forces Air Component Commander-owned theater asset for reconnaissance, surveillance and target acquisition in support of the Joint Forces Commander.

The basic crew is one pilot and two sensor operators. They fly the aircraft from inside the ground control station via a line-of-sight data link or a satellite data link for beyond line-of-sight flight.

35

Thesis Experiment
- Phase 3: Experiment -

General information

The aircraft is equipped with a color camera in the nose (generally used by the pilot for flight control), a day variable-aperture TV camera, a variable-aperture infrared (IR) camera (for low light/night), and a synthetic aperture radar (SAR) for looking through smoke, clouds or haze. The cameras produce full motion video while the SAR produces still-frame radar images.

For this experiment there will be a slight change. The nose camera will be switched off since your main focus will be on your instruments. This would be equivalent to flying in conditions of poor visibility.

36

Thesis Experiment
- Phase 3: Experiment -

The Task

Your duty station is the Ground Control Station, located in Monterey, at the Naval Postgraduate School.

To gain a better understanding about the work of an operator of a Predator, please view this video by pressing

Note:
Close the video by clicking on x of windowsmedia player.

37

Thesis Experiment
- Phase 3: Experiment -

Experiment Goals

The goal of this experiment is to test different flight instruments (Traditional HUD and new prototype design WEBER-Box) with different characteristics (color and non-color) for supporting judgment of aircraft attitude.

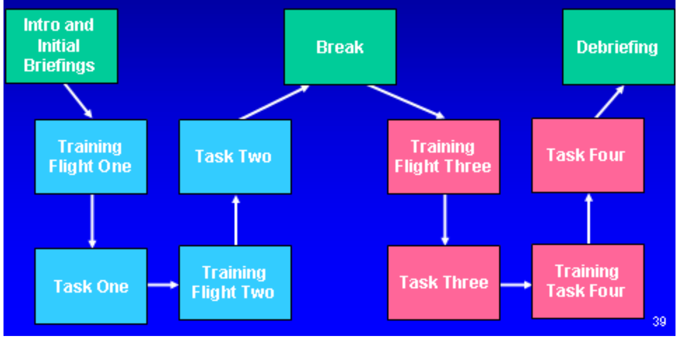
Overall Experiment Schedule

You will conduct four sets of trials. The order in which you will experience the four sets is assigned randomly. The only difference between the four sets is which set of flight instruments is used and if it is color-coded or not.

38

Thesis Experiment
- Phase 3: Experiment -

Experiment Schedule



39

Thesis Experiment
- Phase 3: Experiment -

In each of the four sets of trials, you will see nineteen different attitudes. The first five attitudes are practice trials to get familiar with the task and the remaining fourteens are for the test.

Each time you will see a screen shot of a flight simulation that lasts for ten seconds. This is the time available to you to judge whether the current aircraft attitude is *usual* or *unusual*. You will respond as quickly as possible by telling the experimenter "*unusual attitude*" or "*usual attitude*."

Don't forget that you have a maximum of only ten seconds for your judgment since the simulation can't be stopped.

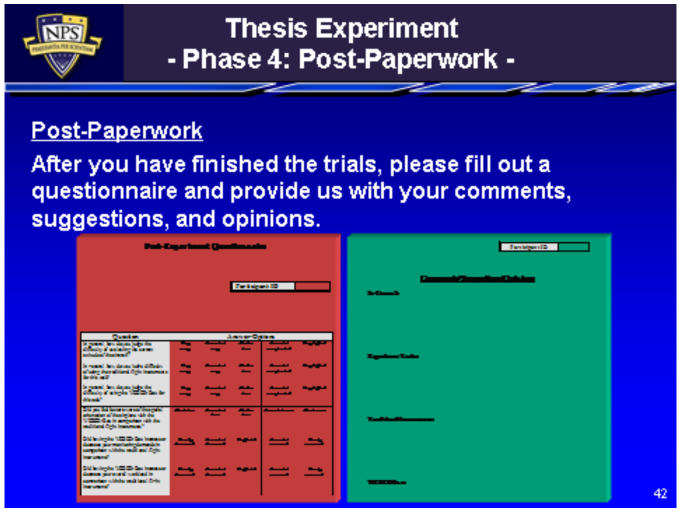
40

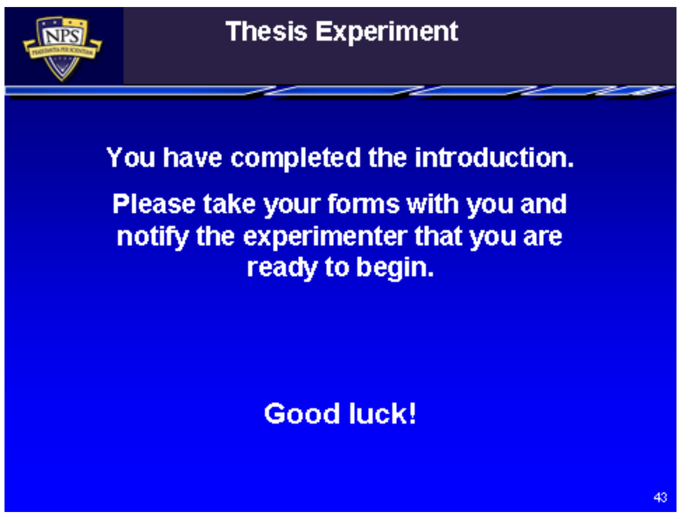
Thesis Experiment
- Phase 3: Experiment -

Remember! Remember!

- You are a volunteer and we truly appreciate your time and willingness to participate in our experiment!
- Do not put yourself under pressure, even though some tasks might be challenging.
- Please complete all trials if possible, but you can quit the experiment at any time if you need to.
- All personal data will be handled confidentially and anonymously.

41


Thesis Experiment
- Phase 4: Post-Paperwork -
Post-Paperwork
After you have finished the trials, please fill out a questionnaire and provide us with your comments, suggestions, and opinions.
42


Thesis Experiment
You have completed the introduction.
Please take your forms with you and notify the experimenter that you are ready to begin.
Good luck!
43

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APPENDIX E. PARTICIPANT CONSENT FORM & MINIMAL RISK STATEMENT

Naval Postgraduate School

Participant Consent Form & Minimal Risk Consent Statement

Introduction. You are invited to participate in a study entitled **Pictorial Display Design to enhance Spatial Awareness of Operators in Unmanned Aviation** being conducted by the Naval Postgraduate School MOVES Institute.

Procedures. If I agree to participate in this study, I understand that I will be provided with an explanation of the purposes of the research, a description of the procedures to be used, identification of any experimental procedures, and the expected duration of my participation.

Synopsis: There will be two sessions: (1) a 30 minute test phase with traditional flight instruments and (2) a 30 minute test phase with the new prototype display design, during which you will be expected to accomplish a number of tasks related to orientation during flight operations.

Risks and Benefits. I understand that this project does not involve greater than minimal risk and involves no known reasonably foreseeable risks or hazards greater than those encountered in everyday life. I understand that there is a very small chance that susceptible participants could experience symptoms of simulator sickness such as "queasy" stomach. I agree that, if I do experience such symptoms, I will remain in the testing area until they have subsided. I have also been informed of any benefits to myself or to others that may reasonably be expected as a result of this research.

Compensation. I understand that no tangible reward will be given. I understand that a copy of the research results will be available at the conclusion of the experiment.

Confidentiality & Privacy Act. I understand that all records of this study will be kept confidential and that my privacy will be safeguarded. No information will be publicly accessible which could identify me as a participant, and I will be identified only as a code number on all research forms. I understand that records of my participation will be maintained by NPS for five years, after which they will be destroyed.

Voluntary Nature of the Study. I understand that my participation is strictly voluntary, and if I agree to participate, I am free to withdraw at any time without prejudice.

Points of Contact. I understand that if I have any questions or comments regarding this project upon the completion of my participation, I should contact the Principal Investigator, Dr. Michael E. McCauley, 656-2191, memccaul@nps.edu. Any medical questions should be addressed to LTC Eric Morgan, MC, USA, (CO, POM Medical Clinic), (831) 242-7550, eric.morgan@nw.amedd.army.mil. Any other questions or concerns may be addressed to the IRB Chair, LT Brent Olde, 656-3807, baolde@nps.edu.

Statement of Consent. I have read and understand the above information. I have asked all questions and have had my questions answered. I agree to participate in this study. I will be provided with a copy of this form for my records.

______________________________	______________
Participant's Signature	Date
______________________________	______________
Researcher's Signature	Date

APPENDIX F. PRIVACY ACT STATEMENT

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943

PRIVACY ACT STATEMENT

1. Purpose: Spatial cognition data will be collected to enhance knowledge, and to develop tests, procedures, and equipment to improve the development of Virtual Environments.

2. Use: Spatial cognition data will be used for statistical analysis by the Departments of the Navy and Defense, and other U.S. Government agencies, provided this use is compatible with the purpose for which the information was collected. Use of the information may be granted to legitimate non-government agencies or individuals by the Naval Postgraduate School in accordance with the provisions of the Freedom of Information Act.

3. Disclosure/Confidentiality:

   a. I have been assured that my privacy will be safeguarded. I will be assigned a control or code number which thereafter will be the only identifying entry on any of the research records. The Principal Investigator will maintain the cross-reference between name and control number. It will be decoded only when beneficial to me or if some circumstances, which is not apparent at this time, would make it clear that decoding would enhance the value of the research data. In all cases, the provisions of the Privacy Act Statement will be honored.

   b. I understand that a record of the information contained in this Consent Statement or derived from the experiment described herein will be retained permanently at the Naval Postgraduate School or by higher authority. I voluntarily agree to its disclosure to agencies or individuals indicated in paragraph 3 and I have been informed that failure to agree to such disclosure may negate the purpose for which the experiment was conducted.

   c. I also understand that disclosure of the requested information, including my Social Security Number, is voluntary.

____

Name, Grade/Rank (if applicable)
[Please print]

____

Signature of Volunteer Date

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APPENDIX G. INITIAL QUESTIONNAIRE

Initial Questionnaire

Date:

Leave blank!

Participant ID	

Age	
Gender	**Male** ☐ **Female** ☐

Are you experienced in aviation in any regard (incl. playing Flight Simulation Games)?	**YES** ☐	**NO** ☐

If you answered the last question with YES, please proceed HERE.

Are you an aviator/pilot?	**YES** ☐	**NO** ☐
Are you familiar with the basic set of flight instruments?	**YES** ☐	**NO** ☐
Are you familiar with the basic aircraft flight controls?	**YES** ☐	**NO** ☐
Did you operate any of these aircraft?: **Fixed-Wing (Jet/Propeller)** **Rotor-Wing Aircraft** **UAV**	**Fixed** ☐ **Jet** ☐ **UAV** ☐	**Rotor** ☐ **Propeller** ☐
How many flight hours do you have?		**Hours**
How many hours in a flight simulator do you have?		**Hours**
How long ago was your last flight?	**Years**	**Month(s)**
How long ago was your last use of a flight simulator?	**Years**	**Month(s)**
Are you trained in procedures of recovery from unusual attitude?	**YES** ☐	**NO** ☐

Leave blank!

Participant ID	

If you are an active/former aviator/pilot, please proceed HERE:

Have you ever experienced any kind of Spatial Disorientation?	**YES** ☐ **NO** ☐
More than once?	**YES** ☐ **NO** ☐
Briefly describe the situation/s	

PLEASE STOP HERE!

APPENDIX H. POST-EXPERIMENT QUESTIONNAIRE

Post-Experiment Questionnaire

Leave blank!

Participant ID	

Question	Answer-Options				
In general, how do you judge the difficulty of evaluating the current attitude of the aircraft?	*Very easy*	*Somewhat easy*	*Border line*	*Somewhat complicated*	*Very difficult*
In general, how do you judge difficulty of using the traditional flight instruments for this task?	*Very easy*	*Somewhat easy*	*Border line*	*Somewhat complicated*	*Very difficult*
In general, how do you judge the difficulty of using the WEBER-Box for this task?	*Very easy*	*Somewhat easy*	*Border line*	*Somewhat complicated*	*Very difficult*
In general, how do you judge the benefits of color coding of an unusual attitude?	*Very good*	*Somewhat good*	*Border line*	*Somewhat poor*	*Very poor*
Did you feel better aware of the spatial orientation of the airplane with the WEBER-Box in comparison with the traditional flight instruments, when both are without color coding of an unusual attitude?	*Much less*	*Somewhat less*	*Border line*	*Somewhat more*	*Much more*
Did you feel better aware of the spatial orientation of the airplane with the WEBER-Box in comparison with the traditional flight instruments, when both are with color coding of an unusual attitude?	*Much less*	*Somewhat less*	*Border line*	*Somewhat more*	*Much more*
Did having the WEBER-Box increase or decrease your monitoring demands in comparison with the traditional flight instruments?	*Greatly decreased*	*Somewhat decreased*	*Unaffected*	*Somewhat increased*	*Greatly increased*

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APPENDIX I. COMMENTS/ SUGGESTIONS/ OPINIONS

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Participant ID	

<u>Comments/Suggestions/Opinions</u>

In General:

Experiment Tasks:

Traditional Instruments:

WEBER-Box:

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APPENDIX J. ORDER OF TRIALS

Order of Trials

Project Study 02

Participant			Order			
1.	S01	NP	A	B	C	D
2.	S10	P	B	C	D	A
3.	S02	NP	C	D	A	B

Experiment

Participant			Order			
1.	201	NP	A	B	C	D
2.	101	P	B	C	D	A
3.	202	NP	C	D	A	B
4.	001	P	D	A	B	C
5.	203	NP	A	B	C	D
6.	002	P	B	C	D	A
7.	003	P	C	D	A	B
8.	004	P	D	A	B	C
9.	005	P	A	B	C	D
10.	204	NP	B	C	D	A
11.	205	NP	C	D	A	B
12.	006	P	D	A	B	C
13.	206	NP	A	B	C	D
14.	207	NP	B	C	D	A
15.	007	P	C	D	A	B
16.	208	NP	D	A	B	C
17.	209	NP	A	B	C	D
18.	008	P	B	C	D	A
19.	102	P	C	D	A	B
20.	210	NP	D	A	B	C

Legend:
A: Traditional Design without color
B: Prototype Design without color
C: Traditional Design with color
D: Prototype Design with color

P: Pilot
NP: Non-Pilot

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APPENDIX K: EVALUATION FORM

Participant ID	

Start with Traditional Design without color: **A** ☐

Trails	Attitude			correct	incorr.	Time
1 – test trial	A	usual	*pitch 15° nose up*			
2 – test trial	B	usual	*bank angle 25° left*			
3 – test trail	C	unusual	*bank angle 60° right*			
4 – test trail	D	unusual	*pitch 15° nose down*			
5 – test trail	E	unusual	*pitch 35° nose up & bank angle 55° left*			
6	M	unusual	pitch 30° nose up			
7	H	usual	bank angle 35° left			
8	J	usual	pitch 10° nose up & bank angle 20° right			
9	O	unusual	bank angle 65° left			
10	G	usual	pitch 05° nose down			
11	Q	unusual	pitch 05° nose down & bank angle 55° left			
12	N	unusual	pitch 20° nose down			
13	F	usual	pitch 20° nose up			
14	P	unusual	bank angle 55° right			
15	R	unusual	pitch 25° nose down & bank angle 35° left			
16	K	usual	pitch 05° nose down & bank angle 35° left			
17	I	usual	bank angle 25° right			
18	S	unusual	pitch 40° nose up & bank angle 60° right			
19	L	usual	pitch 5° nose down & bank angle 25° right			

Start with <u>Traditional Design with color</u>: **C** ☐

Trails	Attitude			correct	incorr.	Time
1 – test trial	A	usual	*pitch 15° nose up*			
2 – test trial	B	usual	*bank angle 25° left*			
3 – test trail	C	unusual	*bank angle 60° right*			
4 – test trail	D	unusual	*pitch 15° nose down*			
5 – test trail	E	unusual	*pitch 35° nose up & bank angle 55° left*			
6	P	unusual	bank angle 55° right			
7	M	unusual	pitch 30° nose up			
8	K	usual	pitch 05° nose down & bank angle 35° left			
9	N	unusual	pitch 20° nose down			
10	I	usual	bank angle 25° right			
11	J	usual	pitch 10° nose up & bank angle 20° right			
12	O	unusual	bank angle 65° left			
13	S	unusual	pitch 40° nose up & bank angle 60° right			
14	G	usual	pitch 05° nose down			
15	R	unusual	pitch 25° nose down & bank angle 35° left			
16	H	usual	bank angle 35° left			
17	Q	unusual	pitch 05° nose down & bank angle 55° left			
18	L	usual	pitch 5° nose down & bank angle 25° right			
19	F	usual	pitch 20° nose up			

Start with <u>WEBER-Box without color</u>: **B** ☐

Trails	Attitude			correct	incorr.	Time
1 – test trial	A	usual	*pitch 15° nose up*			
2 – test trial	B	usual	*bank angle 25° left*			
3 – test trail	C	unusual	*bank angle 60° right*			
4 – test trail	D	unusual	*pitch 15° nose down*			
5 – test trail	E	unusual	*pitch 35° nose up &* *bank angle 55° left*			
6	I	usual	bank angle 25° right			
7	G	usual	pitch 05° nose down			
8	O	unusual	bank angle 65° left			
9	P	unusual	bank angle 55° right			
10	N	unusual	pitch 20° nose down			
11	H	usual	bank angle 35° left			
12	K	usual	pitch 05° nose down & bank angle 35° left			
13	M	unusual	pitch 30° nose up			
14	F	usual	pitch 20° nose up			
15	Q	unusual	pitch 05° nose down & bank angle 55° left			
16	J	usual	pitch 10° nose up & bank angle 20° right			
17	R	unusual	pitch 25° nose down & bank angle 35° left			
18	L	usual	pitch 5° nose down & bank angle 25° right			
19	S	unusual	pitch 40° nose up & bank angle 60° right			

Start with <u>WEBER-Box with color</u>: **D** ☐

Trails	**Attitude**			**correct**	**incorr.**	**Time**
1 – test trial	A	usual	*pitch 15° nose up*			
2 – test trial	B	usual	*bank angle 25° left*			
3 – test trail	C	unusual	*bank angle 60° right*			
4 – test trail	D	unusual	*pitch 15° nose down*			
5 – test trail	E	unusual	*pitch 35° nose up &* *bank angle 55° left*			
6	Q	unusual	pitch 05° nose down & bank angle 55° left			
7	F	usual	pitch 20° nose up			
8	K	usual	pitch 05° nose down & bank angle 35° left			
9	O	unusual	bank angle 65° left			
10	N	unusual	pitch 20° nose down			
11	R	unusual	pitch 25° nose down & bank angle 35° left			
12	L	usual	pitch 5° nose down & bank angle 25° right			
13	I	usual	bank angle 25° right			
14	M	unusual	pitch 30° nose up			
15	J	usual	pitch 10° nose up & bank angle 20° right			
16	G	usual	pitch 05° nose down			
17	P	unusual	bank angle 55° right			
18	S	unusual	pitch 40° nose up & bank angle 60° right			
19	H	usual	bank angle 35° left			

Legend:

Index	Attitude	Pitch	Bank angle
A	usual	pitch 15° nose up	
B	usual		bank angle 25° left
C	unusual		bank angle 60° right
D	unusual	pitch 15° nose down	
E	unusual	pitch 35° nose up &	bank angle 55° left
F	usual	pitch 20° nose up	
G	usual	pitch 05° nose down	
H	usual		bank angle 35° left
I	usual		bank angle 25° right
J	usual	pitch 10° nose up &	bank angle 20° right
K	usual	pitch 5° nose down &	bank angle 35° left
L	usual	pitch 5° nose down &	bank angle 25° right
M	unusual	pitch 30° nose up	
N	unusual	pitch 20° nose down	
O	unusual		bank angle 65° left
P	unusual		bank angle 55° right
Q	unusual	pitch 5° nose down &	bank angle 55° left
R	unusual	pitch 25° nose down &	bank angle 35° left
S	unusual	pitch 40° nose up &	bank angle 60° right

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